

The Future of Monetary Policy in the Era of Central Bank Digital Currencies (CBDCs): A Comparative Study of CBDCs Strategies and Their Impact on Monetary Policy at the European Central Bank and the Federal Reserve

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BANK DIGITAL CURRENCIES (CBDCs): A COMPARATIVE STUDY OF
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RESERVE

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The completion of this dissertation signifies far more than the conclusion of an academic chapter. It marks the culmination of an enriching journey in which every challenge overcome has shaped not only my academic development but also the person I have become. This journey was characterised by perseverance, the ability to find strength during the most demanding times, and the steadfast support of those who stood by my side. I feel profoundly proud of this achievement and eternally grateful to everyone who believed in me.

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Abstract

This dissertation examines the structural transformation of monetary policy frameworks prompted by the introduction of Central Bank Digital Currencies (CBDCs). It addresses fundamental questions concerning how CBDCs redefine monetary policy tactics and enhance policy efficacy. The theoretical framework synthesises monetary policy with digital finance. Through a comparative analysis of the European Central Bank and the Federal Reserve System, this study assesses how CBDCs may modify both conventional and unconventional policy instruments, as well as transmission channels. The analysis reveals that CBDCs can significantly improve monetary policy transmission through multiple channels: by strengthening the interest rate channel via increased competition for bank deposits and by enabling more precise liquidity management through expanded open market operations. The key conclusions suggest that interest-bearing CBDCs may be particularly impactful, offering a means to overcome the effective lower bound constraint that has limited monetary policy effectiveness in recent times. Furthermore, they can reduce reliance on unconventional tools such as quantitative easing by facilitating the implementation of negative interest rates without triggering a cash conversion response. Although the digital euro is designed as a non-interest-bearing instrument to mitigate the risks of disintermediation, this characteristic may nonetheless enhance monetary policy transmission by fostering greater competition among banks for deposits and improving the pass-through of policy rate changes. Hybrid CBDC models emerge as especially promising, offering a balanced approach to advancing policy effectiveness while safeguarding financial stability. The comparative analysis suggests that the ECB is adopting a more proactive stance, motivated by concerns over monetary sovereignty and financial fragmentation in the euro area, whereas the Federal Reserve remains more cautious, reflecting the global dominance of the U.S. dollar and a lower perceived urgency for digital currency adoption.

JEL codes: E41, E42, E51, E52, E58

Keywords: Central Bank Digital Currency, Monetary Policy Transmission, Digital Financial Innovation, Central Banking Framework.

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List of Abbreviations and Acronyms

AEs	Advanced Economies
AML	Anti-Money Laundering
APP	Asset Purchase Programme
BIS	Bank for International Settlements
BoJ	Bank of Jamaica
BVN	Bank Verification Number
CB	Central Bank
CBOB	Central Bank of The Bahamas
CBDC	Central Bank Digital Currency
CBN	Central Bank of Nigeria
CFT	Combating the Financing of Terrorism
CPMI	Committee on Payments and Market Infrastructures
DSGE	Dynamic Stochastic General Equilibrium
DLT	Distributed Ledger Technology
EA	Euro Area
ECB	European Central Bank
EDPS	European Data Protection Supervisor
ELB	Effective Lower Bound
EONIA	Euro Overnight Index Average
EMEs	Emerging Market Economies
EU	European Union
FED	Federal Reserve
FOMC	Federal Open Market Committee
FTOs	Fine-Tuning Operations

GDP	Gross Domestic Product
HICP	Harmonised Index of Consumer Prices
IORB	Interest on Reserve Balances
KYC	Know Your Customer
LSPAS	Large-Scale Asset Purchases
LTROs	Longer-Term Refinancing Operations
MIT	Massachusetts Institute of Technology
MROs	Main Refinancing Operations
NFC	Near Field Communication
NIRP	Negative Interest Rate Policy
ON RRP	Overnight Reverse Repurchase Agreement (Facility)
OMOs	Open Market Operations
OMT	Outright Monetary Transactions
P2P	Peer-to-Peer
PCE	Personal Consumption Expenditures
PELTROs	Pandemic Emergency Longer-Term Refinancing Operations
PEPP	Pandemic Emergency Purchase Programme
PSPs	Payment Service Providers
PSPP	Public Sector Purchase Programme
QE	Quantitative Easing
Repos	Temporary Repurchase Agreements
Reverse Repo	Reverse Repurchase Agreement
RTGS	Real-Time Gross Settlement
SMP	Securities Markets Programme

TLTROs	Targeted Longer-Term Refinancing Operations
UIP	Uncovered Interest Parity
U.S.	United States of America
WB	World Bank
ZLB	Zero Lower Bound

1. Introduction

The global economy is undergoing a profound transformation, driven by the digital revolution within the monetary domain. Since the advent of Bitcoin in 2009, which introduced a peer-to-peer (P2P) electronic payment system underpinned by a cryptographically secured blockchain (Nakamoto, 2008), this technological development has expanded the scope of digital assets. These advancements have had a significant impact on payment systems, e-commerce, and cross-border transactions. However, despite these developments, the extreme volatility inherent in such digital assets continues to present a substantial barrier to their widespread adoption as viable alternatives to traditional financial instruments. As a result, they are predominantly viewed as speculative assets, characterised by high levels of risk, rather than stable and reliable mediums of exchange or stores of value (Bibi & Canelli, 2024; European Central Bank [ECB], 2021b).

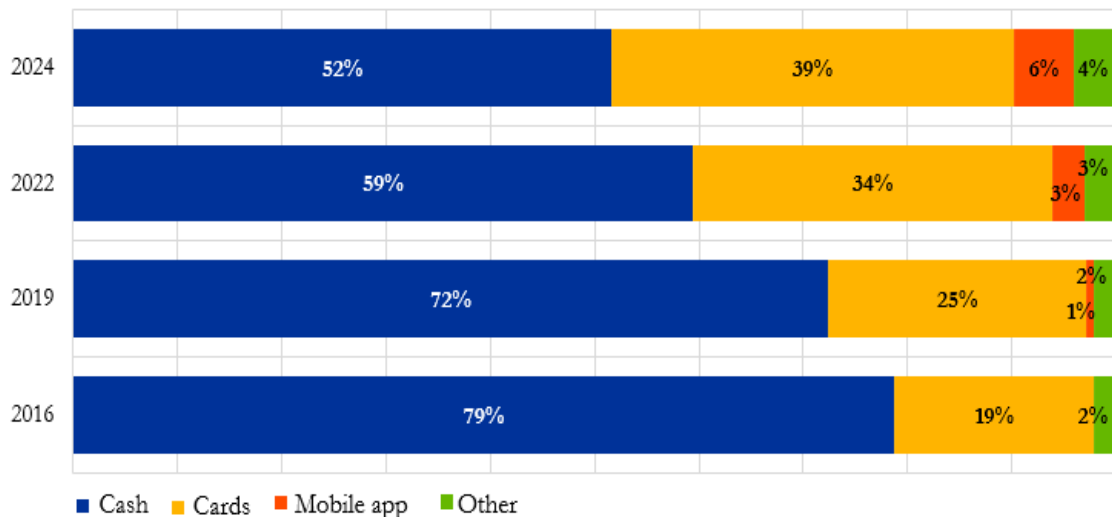
These inherent limitations have led to the emergence of stablecoins, a digital monetary innovation designed to minimise volatility and provide a more stable alternative within decentralised financial ecosystems (Bullmann et al., 2019). These digital assets are typically backed by stable assets, such as fiat currencies, to mitigate price fluctuations. Nevertheless, they face significant challenges, including the requirement for full reserve backing, the risk of issuer insolvency, and the absence of comprehensive regulatory frameworks (Geva & Muraj, 2024).

Furthermore, the widespread adoption of cryptocurrencies, including stablecoins and other digital assets, could undermine the effectiveness of monetary policy by diminishing central banks' control over the money supply and interest rates. If these digital assets were to be extensively used as a store of value, a significant shift of deposits from the traditional banking sector to private digital currencies, such as stablecoins, could weaken the monetary transmission mechanism (Echelpoel et al., 2020; Panetta, 2022). Moreover, should issuers fail to maintain price stability, liquidity pressures and financial stability risks could emerge, constraining central banks' ability to implement monetary policy effectively (Echelpoel et al., 2020; Panetta, 2020). According to Oh and Nguyen (2018), as these digital assets gain traction as media of exchange and stores of value, they may effectively expand the total stock of money circulating in the economy without central bank (CB) oversight. This additional liquidity could place downward pressure on interest rates and stimulate aggregate demand, producing effects akin to expansionary monetary policy (Oh & Nguyen, 2018).

Alongside the emergence of digital alternatives, the monetary system has experienced a sustained decline in cash usage, driven by advancements in payment technologies and the increasing digitalisation of economic transactions. Echarte Fernández et al. (2021) conceptualises this transformation as a natural progression which, while already underway, was markedly accelerated by the COVID-19 pandemic.

Empirical evidence from the Bank for International Settlements (BIS, 2021b), Tamele et al. (2021), and Bibi and Canelli (2024) document a significant rise in digital payments, motivated by both public health considerations and the growing demand for more efficient transaction methods. For example, within the euro area (EA), data from the ECB (2024d) indicate a decline in the share of cash transactions at points of sale from 72% in 2019 to 52% in 2024, signalling a sustained shift in consumer payment behaviour towards digital alternatives. Concurrently, card-based payments have continued to gain prominence, while mobile payment applications, despite their relatively modest overall share, have become increasingly relevant. Figure 1 illustrates the ongoing shift in payment behaviour across the EA, highlighting the decline in cash transactions and the rise of card and mobile payments.

Figure 1. Share of transactions by payment method in the EA (2016–2024)



Source: ECB (2024d).

In response to these innovations and the need to offer greater security and stability, Central Bank Digital Currencies (CBDCs) have emerged as a possible evolution of sovereign money in the digital era, with significant potential to transform the structure of the financial system and the conduct of monetary policy (Adrian & Mancini-Griffoli, 2021; Auer et al.,

2020; Panetta, 2020). Currently, CBs worldwide are conducting rigorous investigations into CBDC implementation, with some countries already launching their digital currencies, fostering significant debate within the economic community regarding potential implications for monetary policy frameworks, financial stability, and payment infrastructures (Atlantic Council, n.d.; Löber & Houben, 2018).

The introduction of CBDCs raises questions about how they might modify traditional monetary policy instruments, particularly considering recent episodes where conventional tools were constrained by the effective lower bound (ELB) on interest rates. This constraint became especially binding after the global financial crisis of 2008 and re-emerged during the COVID-19 pandemic, prompting CBs such as the European Central Bank (ECB) and the Federal Reserve (FED) to adopt large-scale unconventional measures, including asset purchases (quantitative easing, QE) and forward guidance (ECB, 2021; Bernanke, 2020). While the ELB is not presently binding, it constituted a substantial limitation during the 2010s and may once again pose a considerable challenge in the context of future economic contractions.

Academic research presents various perspectives on the impacts of CBDCs on the efficacy of monetary policy. Studies suggest that CBDCs could strengthen policy by potentially eliminating the lower bound on interest rates, thus creating scope for the implementation of negative interest rate policies (Xin & Jiang, 2023a, 2023b). In this regard, Beniak (2019) argues that the effect of CBDCs would be most pronounced through the interest rate channel, particularly affecting deposit rates and the transmission of CB policy rates to lending rates. Moreover, CBDCs have the potential to improve the overall transmission of policy rates, thereby enhancing the precision of monetary responses and offering new transmission channels (Assenmacher et al., 2023; Barrdear & Kumhof, 2022).

In this context, CBDCs, by influencing the way CBs operate in the financial system, particularly through the calibration of interest rates, liquidity management, and the signalling of policy direction, may affect not only the efficacy and the efficiency of monetary policy but also the tactics employed in its implementation. These tactics refer to the selection of means that enable the CB to implement its strategy, encompassing the policy instruments used and the operational and intermediate objectives that guide its actions (Fernandes & Mota, 2023). Given these perspectives, this dissertation addresses two fundamental research questions:

1. How might the implementation of CBDCs redefine the tactics of monetary policy?

2. In what ways do CBDCs potentially enhance the efficacy of monetary policy?

To examine these questions, we focus on the two major CBs in developed economies: the ECB and the FED. Both institutions are responsible for monetary policy in two of the world's largest economic regions and exert a decisive influence on the global financial landscape. The ECB functions as the CB for the EA, the world's third-largest economy in terms of gross domestic product (GDP), after the United States of America (U.S.) and China (ECB, n.d.-b; Orphanides, 2013). It also issues the euro, which is the second most widely used international currency (European Council, 2024). In turn, the FED oversees U.S. economy, the largest globally, and issues the U.S. dollar, which holds the status of the primary global reserve currency, playing a pivotal role in international trade, finance, and the stability of the global financial system (Orphanides, 2013). This role confers upon the FED a singular importance, as its policy decisions have immediate and far-reaching repercussions not only within the U.S. economy but also across the broader global economic and financial dynamics (Orphanides, 2013).

These institutions are among the foremost conducting rigorous investigations into the implementation of CBDC. While the ECB has advanced to a pilot phase with its digital euro project, the FED has shown no indication of proceeding with a retail CBDC (Atlantic Council, n.d.). This contrast in approaches makes them particularly relevant case studies to analyse how digital currency initiatives (or their absence) may impact monetary policy frameworks and to understand the evolving landscape of CB digital innovations.

The "digital euro" and the exploratory work on a "digital dollar" represent strategic responses to the shifting dynamics of the global financial system (ECB, 2020; FED, 2022). Both institutions have identified key objectives including enhanced financial inclusion, improved policy transmission mechanisms, and payment system innovation, alongside operational efficiency gains and environmental sustainability considerations. The implementation challenges of CBDCs have sparked intense policy debates, with prominent political figures raising concerns about their implications for economic freedom and financial privacy (Dorn, 2024). Amidst these complex challenges and potential transformations, the evolving landscape of digital currencies demands rigorous academic scrutiny to understand their profound implications for monetary systems and economic governance.

This dissertation is situated within the scientific field of monetary policy, with significant implications for financial markets, central banking, and digital finance. It is grounded in the

hypothesis that CBDCs may enable CBs to adopt a more flexible and innovative approach to monetary policy, potentially overcoming constraints inherent in traditional instruments. It also anticipates that the integration of CBDCs will enhance the transmission mechanisms and overall efficacy of CB actions. In pursuit of this hypothesis, the research undertakes a critical evaluation of potential modifications to core conventional and unconventional monetary policy tools, with particular attention given to scenarios of economic distress and prolonged low-interest rate environments.

Thus, this dissertation offers three distinct academic contributions. First, it transcends the boundaries of isolated case studies by comparatively exploring how different institutional and economic contexts shape CBDC implementation strategies by two important CBs. Second, it develops an analytical framework to assess how CBDC design features, particularly the distinction between interest-bearing and non-interest-bearing models, affect monetary policy transmission mechanisms and the effectiveness of conventional and unconventional policy tools.

Finally, it presents evidence from the literature on how institutional differences, such as the unique role of the euro as a single currency in a multinational union, in contrast to the global dominance of the dollar, can affect the decision to implement a CBDC, and how the design adopted can affect the effectiveness of monetary policy implementation. In this sense, this dissertation aims not only to enrich the academic discourse, but also to provide practical contributions for the future conduct of monetary policy in a rapidly digitalizing environment.

The structure of this dissertation is organized as follows: Chapter 2 outlines the contemporary monetary architecture, providing the necessary foundation for understanding CBDCs. Chapter 3 develops the conceptual framework of CBDCs and examines their potential influence on monetary policy. Chapter 4 explores the implications of CBDCs for monetary policy implementation. Chapter 5 discusses CBDC implementation experiences across selected jurisdictions, namely the Bahamas, Nigeria, and Jamaica. Chapter 6 presents an institutional comparative analysis, focusing on the ECB and the FED and their respective CBDC initiatives. Chapter 7 discusses the key findings and their implications, and Chapter 8, the conclusion, with a summary of the main results and suggestions for future research.

2. Contemporary Monetary Architecture

The intricate dynamics of the contemporary monetary system and the complexities of policy transmission mechanisms require a rigorous examination of the interdependent relationship between CB and commercial banks within the broader monetary architecture. A thorough analysis of this interaction is essential to assessing the potential implications of CBDC implementation for the effectiveness of monetary policy and the transmission of its instruments throughout the financial system.

A CB is a sovereign monetary institution tasked with regulating the issuance and circulation of currency within a given jurisdiction or monetary union (ECB, 2015). It fulfils a fundamental role in managing the liquidity conditions to ensure macroeconomic stability, facilitate monetary policy implementation, and support broader economic objectives (ECB, 2015). A CB formulates and implements monetary policy primarily through the targeting of short-term interest rates as operational objectives, which serve as the fundamental "cost of money", influencing credit conditions, capital allocations, and aggregate economic activity (ECB, 2015). The monetary authority manages liquidity through instruments such as Open Market Operations (OMOs), standing facilities, and minimum reserve requirements, thereby anchoring market interest rates around policy rates and ensuring the effective transmission of policy measures to the broader interest rate structure (Dobler et al., 2016; Fernandes & Mota, 2023; Mankiw, 2020).

Beyond these core monetary policy functions, the CB takes on a critical role as the lender of last resort within the financial system. This function involves providing credit support through various lending facilities, such as the discount window in the FED's operations, which are made available at the discretion of CBs (Dobler et al., 2016). In the event of systemic shocks, the CB can deploy auction-type mechanisms to ensure continued market functioning. This dual approach is designed to preserve financial stability and ensure the availability of adequate liquidity during periods of economic distress. The CBs' capacity to fulfil this role stems from its unique ability to create CB money *ex nihilo*, contingent upon sustained confidence in the stability of its value relative to goods and services (Tucker, 2014).

Commercial banks participate in the process of money creation through a specific mechanism: the creation of demand deposits facilitated by the extension of credit. When a loan is granted, the bank simultaneously generates a deposit of an equivalent amount in the borrower's account (McLeay et al., 2014). The volume of lending undertaken is determined

by the profitability of credit opportunities, which is significantly influenced by the interest rate set by the CB, such as the policy rate and deposit rate. While the policy rate affects short-term interest rates and consequently the cost of credit for commercial banks, the deposit rate determines returns on reserves held at the CB (Singh, 2023). For instance, lower or negative deposit rates on excess reserves provide an incentive for banks to expand credit supply rather than holding large volumes of reserves. This lending activity leads to the creation of corresponding deposits, thereby driving the demand for additional reserves to meet liquidity obligations, such as withdrawals, interbank transfers, and regulatory requirements. Under normal circumstances, the CB accommodates this demand for reserves, ensuring monetary and financial stability (Jakab & Kumhof, 2015; McLeay et al., 2014). This process results in the creation of new money, subject to the liquidity needs of economic agents.

It is fundamental to make a distinction between three forms of assets in the modern monetary system: CB money (numeraire), reserves (monetary base component) and private money (deposits) (Committee on Payments and Market Infrastructures [CPMI], 2015). Currency, as the only form of CB money accessible to the public, enables direct transactions without intermediaries and holds legal tender status, ensuring its mandatory acceptance in payments (European Data Protection Supervisor [EDPS], 2023). In contrast, bank deposits are created by commercial banks through the credit creation process, constituting the predominant form of money utilised in the economy. The confidence of depositors and regulatory framework determine their acceptance and convertibility into currency, whilst their usage influences the liquidity and reserve requirements of financial institutions (EDPS, 2023; Smith, 1966). Moreover, bank reserves represent a form of CB liability exclusive to financial institutions, maintained in their accounts. These are utilised for interbank settlements and regulatory requirements, with their volume determined by bank demand and mandatory minimum requirements (Friedman, 1999).

The resulting monetary structure establishes a two-tier system in which CB money, consisting of currency in circulation to the public, coexists with commercial bank money. This integrated monetary framework facilitates economic transactions and financial intermediation, while highlighting the CB's pivotal role in managing monetary policy and serving as the ultimate guarantor of liquidity within the financial system. Furthermore, this framework provides a fundamental basis for understanding the potential implications of the introduction of CBDCs on the financial system and monetary policy.

3. Conceptual Framework of CBDC

The literature conceptualizes CBDCs as a new monetary instrument that preserves the key attributes of sovereign currency by adapting them to the digital age. Kiff et al. (2020) and Allen et al. (2020) define CBDCs as digital representations of sovereign currency that constitute liabilities of the CB. This definition is further developed by the BIS (2020), which characterises CBDCs as digital payment instruments, denominated in the national unit of account and directly supported by the CB, emphasising their intended use for everyday transactions by the public. In addition to their legal and institutional nature, CBDCs also perform essential monetary functions. As Lee et al. (2021) note, they assume the three classic roles of money: store of value, unit of account, and medium of exchange. In this context, the FED (2022) highlights that, by being made available in digital format, CBDCs preserve the advantages of traditional currency issued by CB, namely security, liquidity, and reliability, thus becoming a form of money adjusted to the demands of the digital economy.

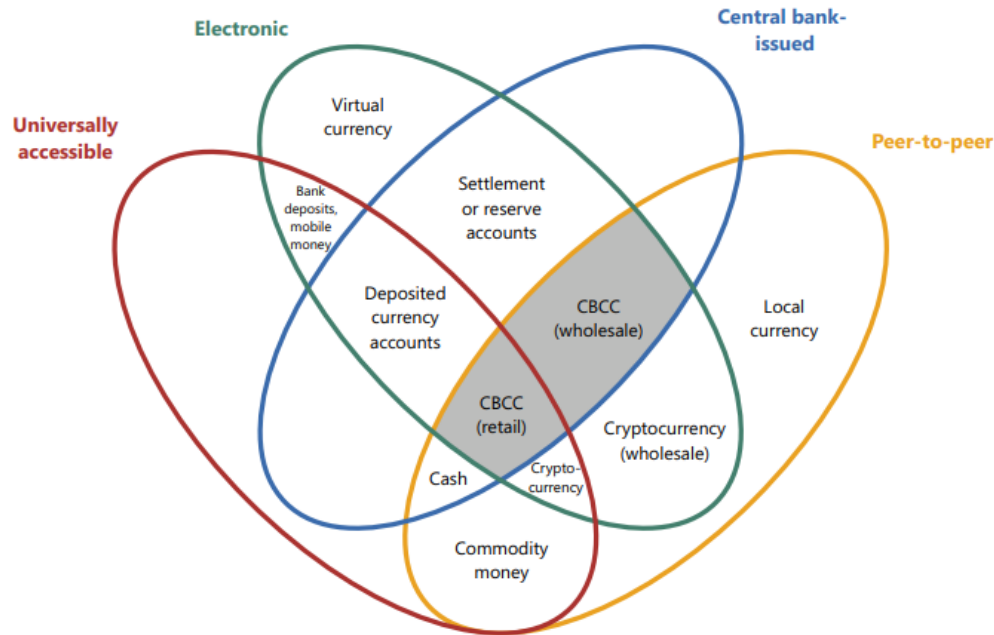
Although both CBDCs and cryptocurrencies are digital by nature, they differ fundamentally in their characteristics and intended purposes. Unlike CBDCs, which are issued and regulated by CBs, cryptocurrencies are decentralised digital assets that operate on distributed ledger technology (DLT) without the backing or liability of any sovereign authority. According to CPMI (2015), cryptocurrencies can be characterised by three key features: they are purely electronic, facilitate P2P transactions, and do not represent a liability of any issuing entity.

Moreover, Bjerg (2017) establishes a clear distinction between CBDCs and other existing forms of money: currency, which lacks an electronic nature; bank reserves, which are restricted to financial institutions; and bank deposits, which, despite being electronic, are not issued by a CB. Based on these distinctions, the author defines the CBDC as "electronic"; "universally accessible"; and "issued by a CB." The issue of accessibility and universality is particularly emphasised in the convergent analyses of Kumhof and Noone (2018), Meaning et al. (2021), and Auer et al. (2020), technically distinguishing it from traditional reserve balances.

The Money Flower taxonomy, developed by Bech and Garratt (2017), provides a systematic classification of CBDCs and their interrelationship with other forms of money. Figure 2 illustrates this taxonomy, which results from the combination of the CPMI (2015)

and Bjerg (2017) approaches, highlighting the position of CBDCs within the context of different existing forms of money.

Figure 2. The money flower: a taxonomy of money



Source: Bech e Garratt (2017).

In this context, sovereign digital currency is defined as an electronic form of money issued by the CB, capable of being exchanged in a decentralised manner. Transactions occur directly between the payer and the payee, without requiring a central authority as an intermediary (Bech & Garratt, 2017). This feature differentiates CBDCs from other forms of electronic money issued by CBs, such as reserves, which are processed through a centralised system where transactions take place exclusively between accounts held at the issuing institution.

The purpose and underlying objectives of introducing a CBDC play a pivotal role in its design, as its formulation must be rigorously aligned with the objectives defined by the CB (Auer et al., 2020). However, the different economic characteristics and specific requirements of each jurisdiction generate different interpretations and approaches to sovereign digital currencies (Lee et al., 2021). Indeed, surveys conducted by several CBs, notably by Boar et al. (2020) and subsequently by Kosse and Mattei (2022), indicate that advanced economies (AEs) and emerging market economies (EMEs) set different priorities in the implementation of CBDCs. This divergence in motivation underscores the importance of assessing the potential implications for the global financial system. As a result, CBDCs

are expected to fundamentally reshape the structure of financial transactions by enhancing efficiency and security, while simultaneously reinforcing CB's capacity to implement monetary policy. Against this backdrop, the following sections will explore the different strategies adopted in the design and implementation of CBDCs.

3.1. Classification of CBDCs

The classification of CBDCs is essential to understand their distinct functions and potential impacts within the financial system. In the context of their design and implementation, CBDCs can be broadly divided into two main categories: retail and wholesale, as evidenced in Figure 2 (Bech & Garratt, 2017). Each of these variants takes distinct forms, designed for specific purposes: retail CBDCs are targeted at the general public, while wholesale ones are restricted to financial institutions (Athanassiou, 2020). Beyond the differentiation in terms of target audience, these variants also vary in key aspects such as their digital-only format, the degree of use permitted, and the potential to support P2P transactions. Such differences reflect the diverse objectives underlying each model and highlight their potential to shape future monetary policy frameworks.

In this regard, retail CBDCs are particularly relevant, as they are intended for use by households and non-financial companies and can function simultaneously as a means of payment and a store of value (Infante et al., 2024). In AEs, their development is primarily aimed at improving payment efficiency, strengthening financial stability, and ensuring continued public access to CB-issued money (Boar et al., 2020; Kosse e Matei, 2022). In EMEs, the focus lies mainly on promoting financial inclusion, especially among unbanked populations, in addition to ensuring greater efficiency and resilience in payment systems (Boar et al., 2020; Infante et al., 2024; Kosse & Mattei, 2022; Lee et al., 2021; Morales-Resendiz et al., 2021).

However, the implementation of retail CBDCs in EMEs faces significant obstacles. Foster et al. (2021) underline the structural challenges posed by institutional limitations and deficiencies in technological infrastructure. Such weaknesses may compromise the effectiveness of CBDC adoption, exposing these economies to risks associated with the use of foreign stablecoins and other private digital currencies. In addition, high connectivity costs

and low digital penetration may limit access for the most vulnerable population groups, precisely those who would benefit most from financial inclusion solutions.

Regarding functionality, Bech and Garratt (2017) suggest that retail CBDCs may offer a certain degree of anonymity in P2P transactions. However, in contexts where anonymity is not considered essential, the same objectives may be achieved by extending access to CB accounts. Effective implementation of this modality requires coexistence with physical cash, collaboration between the public and private sectors, and significant investment in technological infrastructure (BIS, 2020). To ensure acceptance and effectiveness, CBDCs must be secure, interoperable, and affordable, supported by a robust regulatory framework that underpins trust in the financial system (Infante et al., 2024).

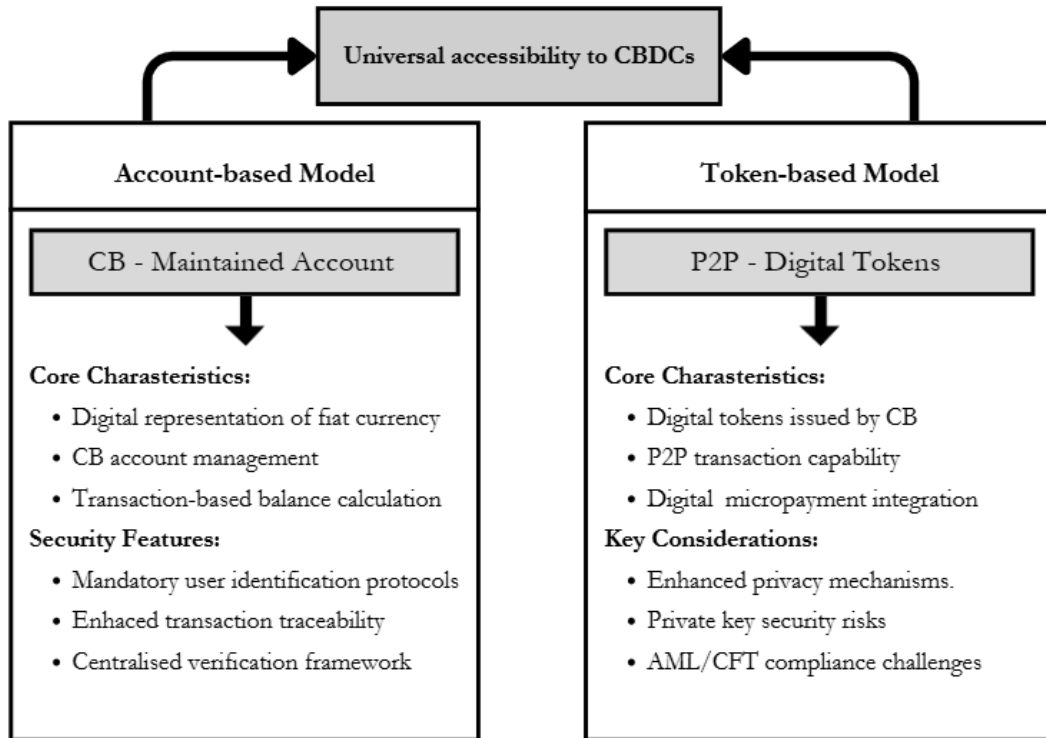
In contrast, wholesale CBDCs are designed for the exclusive use of authorised financial institutions, such as commercial banks and other entities participating in interbank settlement systems (Opare & Kim, 2020; Schumacher, 2024a). These digital solutions aim to modernise and enhance the efficiency of the interbank market, including through the adoption of technologies such as tokenised platforms, programmability, and composability (Athanassiou, 2020; Durfee et al., 2023). Their introduction is justified by the need to reduce operational costs and increase the speed and security of financial settlements (Bech & Garratt, 2017). The issuance, distribution, and maintenance of wholesale CBDCs fall under the exclusive responsibility of the CB or an entity designated by it, and all transactions occur centrally, without ensuring anonymity but safeguarding the institutional privacy of participants (Opare & Kim, 2020).

3.2. Implementation Models

The literature identifies two fundamental approaches to the implementation of retail CBDCs: the account-based model and the token-based model (Auer & Böhme, 2020). Although these models differ in their technical and operational mechanisms, they share the central objective of ensuring universal access to digital currency. This typology is based on the underlying mechanisms of payment processing, either through balance updates or the registration of asset ownership (BIS, 2021a). While both models require some form of accounting record, they offer varying degrees of user identification, ranging from anonymity to full disclosure.

As illustrated in Figure 3, these architectures aim to foster broad participation in the digital currency ecosystem, albeit through distinct methods of identity verification, transaction validation, and system security.

Figure 3. Model of Implementation of a CBDC



Source: Authors own based on Auer and Böhme (2020).

In this context, it is useful to examine each model more closely, beginning with the account-based approach. This model entails the maintenance of digital representations of fiat currency in accounts directly held by the CB. This structure mirrors traditional banking systems, where balances are determined through sequential transaction recording and reconciliation. As noted by Schumacher (2024c) and Auer and Böhme (2020), a distinguishing feature of this model is the requirement for mandatory identification for access to accounts, thereby establishing a rigorous framework for traceability and transaction security.

Conversely, the token-based model facilitates P2P transactions using representations of CB-issued currency, allowing for payments without the need for a direct bank account connection, much like physical cash, where possession of the token is sufficient for transaction validation (Auer et al., 2020). This approach offers enhanced privacy features and is particularly well-suited for integration with micropayment systems on digital platforms. However, it also presents notable challenges. Auer and Böhme (2020) point out that users

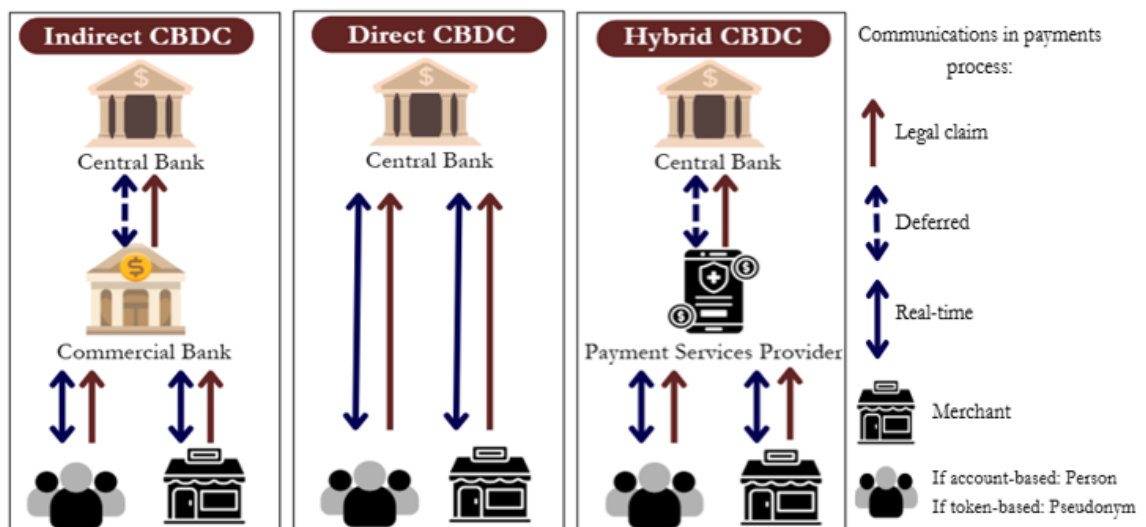
face significant operational risks, especially the potential loss of funds due to inadequate private key management. Additionally, the model complicates compliance with Anti-Money Laundering (AML) and Combating the Financing of Terrorism (CFT) regulations, making it difficult to effectively track transactions and identify token holders (Auer & Böhme, 2020).

A comparative assessment of these two models reveals structural differences that are critical for the design of a retail CBDC, particularly in the balance between centralised control and operational autonomy. Beyond technical considerations, such choices bear direct implications for the institutional configuration of digital currency and its potential influence on the conduct of monetary policy. As noted by Guley and Koldovskyi (2023) and Mu and Mu (2022), direct issuance of this digital currency by the CB represents more than a payment system upgrade. It constitutes a structural change with significant implications for monetary transmission, policy implementation, systemic resilience, and cross-border transaction efficiency, each of which will be addressed in Chapter 4.

3.3. Architectural Models

The macroeconomic effects of a CBDC depend fundamentally on its operational architecture and design. In particular, specific design features will shape its implications for financial stability, monetary policy, and the functioning of payment systems (Löber & Houben, 2018). Figure 4 presents a simplified representation of the CBDC design proposals, classified into three distinct architectural models, as outlined by Auer and Böhme (2020).

Figure 4. Potential Design Architectures for Retail CBDC



Source: Author's own based on Auer and Böhme (2020).

One of the four models is the indirect CBDC architecture, which maintains the traditional two-tier banking structure, preserving the fundamental role of financial intermediaries within the monetary system (Auer & Böhme, 2020). In this model, intermediary institutions hold corresponding reserves at the CB while retaining responsibility for consumer interface and payment system operations, with final settlement remaining centralized within the monetary authority. From a technical infrastructure perspective, this model typically employs conventional database systems operating through a centralised hierarchical structure.

In contrast to the indirect model, the direct CBDC architecture fundamentally alters the traditional monetary systems by establishing direct operational relationships between CBs and end users, bypassing conventional banking intermediaries (Auer & Böhme, 2020). This model assigns CBs comprehensive responsibility for maintaining transaction ledgers and processing retail payments through centralized systems, where users interact with their accounts via digital interfaces, subject to stringent verification protocols. While offering enhanced systemic control, this model significantly broadens the operational remit of CBs, potentially creating competitive tensions with existing payment service providers (Kiff et al., 2020). The World Bank (WB, 2021) outlines several approaches for direct CBDC architectures: notably, a system that strategically separates personal identification from transaction data to strengthen privacy and cybersecurity measures; a tiered anonymity structure based on transaction thresholds; and a user-centric model enabling controlled information access within AML/CFT regulatory frameworks.

The hybrid CBDC architecture represents a sophisticated synthesis of direct and indirect approaches, offering a nuanced solution to digital currency (Auer & Böhme, 2020). This model strategically preserves the operational role of intermediaries in payment processing while maintaining direct user claims on the CB, thereby combining the efficiency of private sector participation with the security of CB backing. According to the WB (2021), this model enables various implementation approaches, particularly through sophisticated structures whereby Payment Service Providers (PSPs) manage individual accounts while maintaining consolidated omnibus accounts at the CB. A distinguishing characteristic of the hybrid framework is the CBs' maintenance of contingency infrastructure, ensuring operational continuity even in scenarios of intermediary failure. This robust design enhances

system resilience while balancing the benefits of intermediated service delivery with the stability inherent in direct CB claims.

At a structural level, these models differ based on the structure of legal rights and the type of register maintained by the CB, the exclusive entity responsible for the issuance and redemption of CBDCs (Auer & Böhme, 2020). In the indirect model preserves the traditional banking architecture by retaining intermediaries (Auer & Böhme, 2020; Kiff et al., 2020). By contrast, the direct model centralises all functions within the CB, eliminating the need for intermediaries and fundamentally reshaping the monetary architecture. Positioned between these two extremes, the hybrid model aims to strike a balance by allowing intermediaries to manage day-to-day operations while ensuring that end users retain direct claims on the CB (Auer & Böhme, 2020; WB, 2021).

According to Kosse and Mattei (2023), around 87% of CBs exploring CBDCs intend to involve private intermediaries, such as commercial banks or PSPs. Institutions like the Bank of England, the ECB, and the Reserve Bank of India have proposed models consistent with the indirect or hybrid approach. Moreover, 60% of CBs support outsourcing the recording of retail transactions and balance updates to private actors, signalling a growing preference for hybrid models that blend CB control with private sector efficiency.

3.4. Design Features

In terms of design, one of the pioneering frameworks for establishing comprehensive guidelines for the essential design attributes of CBDCs emerged from Löber and Houben (2018), which identifies five critical design dimensions: availability, anonymity, transfer mechanisms, interest-bearing capacity, and operational limitations. This approach outlines essential design attributes to distinguish CBDCs from traditional CB money, as summarised in Table 1.

Table 1. Design features of CBDC

Features	CB Money and Liability		CBDCs	
	Cash	Reserves	Retail	Wholesale
Availability (24/7)	Yes	Restricted to CB operating hours	Possible	Possible
Anonymity	Fully Anonymous	Fully identified	Pseudonymity or full identification	Full traceability
Transfer Mechanism	Disintermediated (P2P)	Centralised intermediation	Flexible: P2P and intermediated	Through financial institutions
Interest- Bearing	No	Yes	Possible	Possible
Limits and Restrictions	No restrictions	Exclusive access to banking system	Possibility of individual limits	Subject to prudential controls

Source: Authors own's based on Löber and Houben (2018).

The implementation of CBDCs requires a meticulous consideration of fundamental policy decisions to determine key features and operational approach. In this context, Löber and Houben (2018) identifies five critical design dimensions: availability, anonymity, transfer mechanisms, interest-bearing capacity, and operational limitations. Commencing with availability, we currently have cash, that is, the physical money issued by the CB, which is permanently available to users. In contrast, electronic money issued by the CB, represented by financial institutions' reserves, is limited to the bank's operating hours, which typically do not cover 24 hours a day or seven days a week, but rather five working days. CBDCs, however, are designed to increase the availability of CB money and can potentially be accessible continuously (24/7) or, depending on the chosen model, during specific periods such as payment system operating hours (Löber & Houben, 2018).

Moreover, CBDCs may incorporate offline capabilities, enabling transactions to be conducted without an internet connection (Chu et al., 2022). This feature endows them with greater resilience when compared to conventional electronic payment systems, ensuring the continuity of payments even during connectivity outages or in regions where digital infrastructure is unreliable or inaccessible.

In terms of transfer mechanisms, Löber and Houben (2018) note that while CB money in the form of cash is transferred on a P2P basis without intermediation, CB liabilities

such as reserves are transferred via the CB itself, acting as a centralised intermediary. In the case of a retail CBDC, transfers may occur on a P2P basis or through an intermediary, such as the CB, a commercial bank or a payment service provider, depending on the adopted architectural model. Conversely, wholesale CBDCs are intended for transfers among financial institutions, typically mediated within existing interbank infrastructures. The architectural design of CBDCs not only determines their transfer mechanisms but also shapes their privacy characteristics. While cash transactions ensure complete anonymity and reserves mandate full identification, retail CBDCs can accommodate varying degrees of privacy, ranging from pseudonymity in token-based systems to comprehensive identification in account-based systems (Löber & Houben, 2018).

The interest-bearing capability represents a particularly significant technical feature, offering enhanced flexibility in monetary policy implementation. Löber and Houben (2018) emphasises that CBDC interest rates can be aligned with existing policy rates or adjusted to influence digital currency demand. This aligns with a design approach proposed by the WB (2021), which suggests that while preserving the core features of a CBDC, incorporating interest-bearing mechanisms could enhance its effectiveness as a monetary policy tool. In this regard, Dyson and Hodgson (2016) further assert that digital currency could enable interest rates to move below the zero lower bound (ZLB), thereby expanding monetary policy capabilities, as will be discussed in the Section 4.2. However, by not bearing interest, CBDC would function like cash, reinforcing its role as an additional form of payment (Das et al., 2023).

Operational considerations extend to the implementation of quantitative limits on CBDC usage and holdings, serving as mechanisms to mitigate potential adverse effects, such as excessive utilisation in large-value transactions. WB (2021) particularly emphasises the efficacy of such controls in account-based systems, where limits can be monitored and enforced with greater precision. This aligns with the Löber and Houben (2018) perspective on the importance of operational safeguards in maintaining financial stability. Various types of quantitative restrictions, in the form of limits or maximum thresholds on CBDC utilisation or holdings, are frequently considered as instruments to mitigate potentially undesirable effects, such as banking disintermediation and the migration of deposits from commercial banks to CBDC deposits (Löber & Houben, 2018).

The multidimensional design framework for CBDCs emphasises the complex interplay between technological capabilities and policy goals that CBs must balance. Rather than merely digitising fiat currency, CBDCs represent a transformative policy tool with significant implications for monetary policy, payment system structure, and financial inclusion. The key challenge lies in harmonising interrelated design elements to create a coherent, context-sensitive architecture that aligns with the specific institutional, economic, and policy environments, ensuring both functional effectiveness and systemic integrity.

3.5. Technical Infrastructure

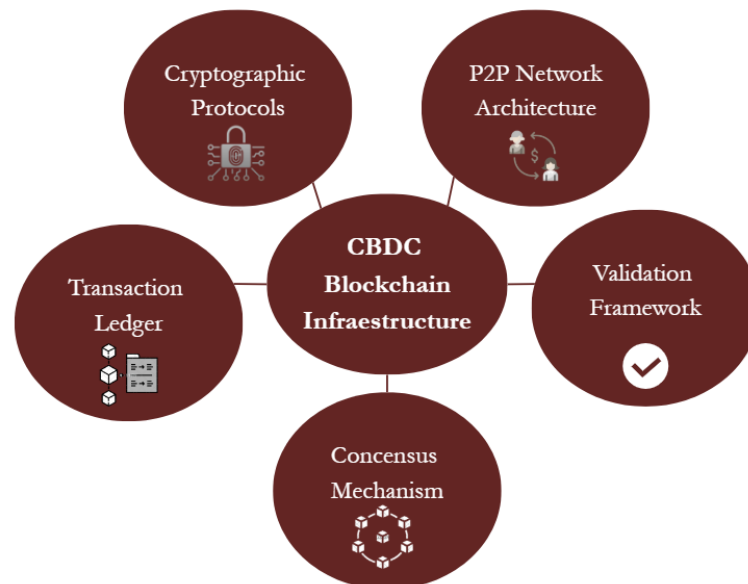
The infrastructural architecture is a critical element in the development and implementation of a CBDC, with direct implications for its operational robustness and systemic resilience. This sovereign digital currency incorporates programmable features, such as smart contracts, which enhance transaction efficiency and reduce intermediation costs (Bank of England, 2020; Zhang & Huang, 2022). These functionalities, along with offline capabilities and tiered privacy mechanisms, are essential for balancing operational resilience, user anonymity, and regulatory compliance. Furthermore, interoperability with existing payment systems is key to the seamless integration of CBDCs into the global financial infrastructure (BIS, 2020).

According to the previously defined architectural models (namely, the indirect, direct, and hybrid CBDC issuance models), the specification of the technological infrastructure is a critical factor in determining both the functional feasibility and structural resilience of the system. As noted by Auer et al. (2020), an indirect CBDC would entail technological and operational requirements for the CB comparable to those observed within the current institutional framework, since financial intermediaries would continue to play a central role in account management and transaction processing. By contrast, under a direct model, where the CB would be solely responsible for executing all retail transactions, substantially more advanced technological capabilities would be required, due to the need to handle transaction volumes comparable to those of the main contemporary electronic payment systems. The hybrid model, although more demanding from an organisational perspective, is technically feasible with current technological resources and deployable in large monetary areas with moderately complex infrastructures.

Two main approaches to digital infrastructure are identified: conventional centralised systems and DLT¹. The latter comprises a decentralised digital infrastructure that stores data in a secure and immutable manner, distributed across multiple independent nodes. This eliminates the need for a central authority and relies on distributed consensus mechanisms and cryptographic validation to manage transactions and update records (Auer et al., 2020; Bech & Garratt, 2017; Kannengießer et al., 2020). This design reduces reliance on intermediaries and mitigates single points of failure, thereby enhancing the overall security and resilience of the system (Bech & Garratt, 2017).

Blockchain technology, a specific form of DLT, enables distributed ledgers and the autonomous verification of transactions on P2P networks without centralised control (Rauchs & Hileman, 2010). By utilising cryptographic mechanisms and advanced consensus algorithms, blockchain ensures decentralisation, traceability, and immutability, thereby reducing dependence on physical infrastructures and intermediaries. This, in turn, facilitates financial inclusion and the digitisation of assets (Swan, 2017; Zhang & Huang, 2022). Figure 5 shows those five key components identified of blockchain infrastructure in the context of CBDC implementation.

Figure 5. Key Components of the Blockchain Infrastructure for CBDCs



Source: Author's own.

¹ Allen et al. (2020) distinguish three technological architectural models for CBDCs: the distributed model, in which multiple devices collaborate to maintain records under centralized coordination; the semi-decentralised model, which shares management among a restricted group of entities, balancing centralised supervision with elements of decentralisation; and the decentralized model, in which trust is distributed among several independent entities, reducing dependence on a single authority and increasing resistance to failure.

The digital ledger constitutes an essential component of these DLT-based architectures, recording transactions in an immutable manner to ensure data integrity and traceability. Its primary function is to verify user balances and ensure that each currency unit is spent only once. Operations are organised sequentially within a single ledger, with each new transaction being based on the state resulting from its predecessors. This model is applied both in centralised systems, employed by financial institutions to manage balances, and in decentralised systems, as exemplified by Bitcoin (Allen et al., 2020; Nakamoto, 2008).

Furthermore, Solat et al. (2021) and Zhang and Huang (2022) identified two fundamental types of blockchain: permissionless, which allows any participant to send and validate transactions without prior authorisation, promoting full decentralisation and resistance to censorship; and permissioned, which restricts participation to authorised entities, ensuring greater control, regulatory compliance, and operational efficiency, features aligned with the objectives of CBs. Zhang and Huang (2022) conclude that the latter is the most suitable for CBDCs. However, the integration of permissioned blockchain into financial systems faces challenges such as performance limitations compared with traditional centralised systems, scalability issues, interoperability, and the need to adapt to varying operational requirements, including offline transactions.

Conversely, conventional centralised systems store data across multiple nodes controlled by a single authorised entity. While such an architecture increases resilience through data replication, it remains vulnerable to systemic risks, particularly cyberattacks targeting the central authority. Although these systems do not rely on consensus mechanisms, they allow for higher transaction throughput but remain exposed to the inherent risk of centralised failure (Auer & Böhme, 2020). Thus, the transition from a centralised to a decentralised model redefines the concept of trust, shifting it from a single entity to the collective validation of the network, which could enhance the security and operational resilience of CBDCs (Auer et al., 2020).

In modern payment infrastructure, Real-Time Gross Settlement (RTGS) systems are key components, particularly relevant for wholesale CBDCs. These systems process the settlement of each transfer instruction individually, in real time and on a gross basis, that is, without netting debits and credits. Operations become final and irrevocable upon settlement, provided the sending institution has sufficient funds or intraday credit (Mañalac et al., 2001; Schumacher, 2024c). RTGS platforms typically automate the processing of electronic

payment messages, settling them against balances held at the CB, thereby ensuring legal certainty and operational efficiency. Within the context of CBDCs, this system is an element in guaranteeing intraday finality and mitigating credit and liquidity risks in high-value transactions. However, their principles are gradually being adapted for retail CBDCs, particularly to ensure immediate and irrevocable settlement between PSPs.

The fundamental distinction between blockchain, RTGS systems, and traditional payment systems lies in the decentralisation, transparency, and immutability offered by DLT. Traditional systems rely on financial intermediaries to validate transactions, while RTGS enhances efficiency by enabling immediate settlement, reducing operational costs and increasing security (Mañalac et al., 2001). Nonetheless, RTGS implementation faces challenges, such as limited accessibility for smaller institutions and high upfront costs, which hinder scalability in less developed markets. To address these limitations, recent studies propose DLT-based architectures that support hierarchical access, including non-bank payment service providers, aiming to improve interoperability and accessibility while maintaining system security and efficiency (Musa et al., 2023).

Given these technological considerations, decisions on whether to adopt a technological model bear significant implications for monetary policy implementation, as the efficiency of payment systems through real-time settlements and reduced unsettled balances significantly improves monetary aggregate measurement. According to Mañalac et al. (2001) and Musa et al. (2023), faster and more secure transactions enable more effective responses by the CB to economic shocks, promoting financial stability and fostering confidence in the financial system. However, Mu and Mu (2022) emphasises concerns about privacy, banking disintermediation, and potential threats to financial stability. Disintermediation is particularly concerning, as it could weaken the traditional bank lending channel, undermining one of the principal mechanisms through which monetary policy affects the real economy.

This trade-off between technological innovation and the preservation of monetary transmission mechanisms implies that CBDCs ought to be designed as extensions of CBs' macroeconomic stabilisation mandate. Consequently, understanding technical features, such as the remuneration of CBDC holdings, is crucial to evaluating their potential impact on the effectiveness of monetary policy transmission, an issue explored in the following chapter.

4. Monetary Policy Implications of a CBDC

The increasing financial digitalisation and subsequent adoption of private digital currencies have weakened CBs' capacity to control systemic liquidity, compromising monetary policy effectiveness (Panetta, 2022). This weakening of CBs' control over systemic liquidity occurs through two interconnected mechanisms: first, a declining demand for CB money; and second, the increasing use of privately issued digital assets in economic transactions.

To address potential disruptions to monetary transmission mechanisms, CBs have begun exploring the development of sovereign digital currencies to reinforce their influence over the financial system. As emphasised by Löber and Houben (2018) and Bordo and Levin (2017), CBDCs enable monetary authorities to maintain control over liquidity mechanisms and interest rate management. Within this context, the present chapter aims to examine the role of CBDCs across both conventional and unconventional monetary policy frameworks, with the primary objective of assessing their implications for monetary policy transmission mechanism.

4.1. Conventional Monetary Policy

The literature explores how CBDCs could fundamentally transform the execution of monetary policy tools, particularly OMOs and reserve requirements. Yang and Zhou (2022) argue that CBDCs have the potential to enhance the implementation of both conventional strategies, enabling greater precision in the application of these traditional instruments.

CBs have employed OMOs as a crucial tool for monetary policy management, primarily to control liquidity and interest rates in financial markets. These operations involve the buying and selling of financial assets, such as government bonds and other collateral-accepted financial instruments, with the aim of adjusting the money supply and influencing credit conditions (ECB, 2025a; FED, 2024). Huber (2023) suggests that the introduction of CBDCs could significantly expand the scope of these operations. Rather than being limited to the purchase and sale of government bonds or other specific financial assets, CB could issue CBDCs directly into the financial markets, offering a more flexible means of managing the money supply. This model would allow CBs greater autonomy and effectiveness in regulating liquidity and interest rates, without relying exclusively on traditional financial

assets. Moreover, the direct issuance of CBDCs to the public and financial institutions would enable a broader distribution of the sovereign digital currency, foster greater financial inclusion and create new forms of interaction within the financial system.

Despite the advantages in terms of flexibility, the introduction of CBDCs is not without its challenges, particularly concerning the management of bank reserves and liquidity forecasting. Lukonga (2023) explore the potential impact of deposit migration. Such displacement raises significant concerns regarding the potential impacts of implementing a retail CBDC under a direct and interest-bearing model on commercial banks' reserves, especially due to the volatility generated by the displacement of deposits. This displacement hampers CB's ability to accurately forecast liquidity requirements, weakening the effectiveness of OMOs as commercial banks' responses to changes in interest rates become slower and less effective.

Research indicates several potential implications for CB operations. Löber and Houben (2018) suggest that, similarly to physical cash, inflows into CBDCs would reduce commercial banks' reserves, necessitating adjustments through OMOs to control short-term interest rates. In a corridor system², such flows would require regular liquidity injection and absorption operations (Lee, 2016). This operational system is still employed by some CB, such as the Czech National Bank and Danmarks Nationalbank (Hansson & Johansson, 2023). In contrast, in a floor system³, currently adopted by the Reserve Bank of Australia, Bank of Canada, the ECB, Reserve Bank of New Zealand, and the FED, requires new interventions only in the event of a significant decline in reserves (Hansson & Johansson, 2023; Lee, 2016).

Moreover, if access to such CBDCs were granted to institutional investors, the interest rate on CBDC holdings could establish an ELB, or "hard floor", for money market rates. This floor would be defined by the CBDC remuneration rate, which, in certain monetary frameworks, could prevent short-term rates from falling below this level (Löber & Houben, 2018). To remain competitive, short-term government securities and repurchase agreements would need to offer yields exceeding that of the CBDC. At the retail level, the

² A corridor system is a monetary policy implementation framework in which the CB sets an upper and lower bound for short-term interest rates and intervenes as needed to maintain the overnight market rate within this corridor (Lee, 2016).

³ A floor system is a framework where the CB supplies excess reserves so that the market interest rate remains close to the deposit facility rate, which serves as an ELB. This reduces the need for frequent liquidity management operations (Lee, 2016).

CBDC would reduce commercial banks' autonomy in setting deposit rates, which would need to be adjusted to align with CBDC rates (Löber & Houben, 2018). This would strengthen the transmission of monetary policy, as changes in the policy rate would be more directly reflected in depositors' returns, this issue will be explored in Section 4.3.

According to Das et al. (2023), in a mid-corridor system targeting a market rate, the demand for CBDCs represents an autonomous factor that may complicate the forecasting of liquidity required to optimise OMOs, particularly during periods of crisis. The volatility associated with CBDC demand can make it more challenging to accurately estimate the reserve needs of banks, as demand for these new payment instruments may exhibit irregular and unpredictable patterns (Lukonga, 2023).

In times of financial instability, this uncertainty can be exacerbated, necessitating more precise liquidity forecasts by CBs. However, CBs could continue to conduct monetary policy operations in a manner like traditional frameworks, maintaining control over reserve interest rates (Das et al., 2023). The communication of interest rate projections remains a crucial tool in influencing term spreads, thereby enabling the continued effectiveness of monetary policy transmission. Thus, while CBDCs introduce additional challenges for liquidity forecasting and the management of OMOs, the efficacy of monetary policy would not be undermined, as CBs would still retain the ability to control the marginal price of reserves, ensuring the stability of the monetary system (Das et al., 2023).

The literature thus reveals a complex and evolving interaction between CBDCs and conventional monetary policy tools. While CBDCs offer potential for enhanced precision and expanded reach in policy implementation, they also present challenges related to bank reserve dynamics and liquidity management. The effectiveness of conventional monetary policy in a CBDC environment will likely depend on specific design choices and the careful calibration of existing tools to accommodate this digital innovation.

4.2. Unconventional Monetary Policy

Negative interest rate policy (NIRP) has become a key tool for several CBs, including the ECB, the Bank of Japan, the Swiss National Bank, the Riksbank, and Denmark's Nationalbank, enabling them to respond to economic conditions characterised by low growth and low inflation (Bindseil, 2020). During the 2008 financial crisis, for example, CBs

lowered short-term interest rates to stimulate aggregate demand, as conventional monetary policy space became exhausted. The ECB followed this trend at a later stage: although it began lowering interest rates in mid-2008, it only introduced negative rates in 2014 (Mota, 2023). In contrast, the FED maintained rates near zero but did not venture into negative territory (see Appendix 1 and Appendix 2 for a detailed analysis of the ECB's and the FED's monetary policy approaches) (Swanson, 2018; Zheng, 2024).

When deposit interest rates (referred to as the deposit facility rate in the context of the ECB) are low or negative, commercial banks' face an increased cost of holding reserves at the CB, which creates an incentive to expand credit and strengthen the monetary policy transmission mechanism. However, when these rates approach the ELB⁴, the effectiveness of conventional monetary policy decreases, as economic agents tend to hold cash to avoid the impact of negative interest rates.

This limit, according to Davoodalhosseini et al. (2020) and Engert and Fung (2017) could be addressed through three mechanisms: (1) restricting cash withdrawals and deposits; (2) removal of high-denomination banknotes; or (3) the elimination of cash altogether. On the other hand, Buiter (2009) suggests two other additional mechanisms to address this limitation: (4) impose a tax on cash or (5) decouple the function of money as a unit of account from its use as a medium of exchange.

However, Davoodalhosseini et al. (2020) argue that a more effective alternative would be to replace physical cash with an interest-bearing CBDC, allowing the application of negative interest rates more effectively and without causing major distortions, unlike the previously mentioned alternatives. These digital currencies should be designed to accrue interest, positive or negative, and could enhance the efficiency of payment systems through the implementation of sophisticated transfer mechanisms that adjust interest rates depending on the balance held in the digital account. This system makes it possible to maintain adequate levels of liquidity and to establish a more flexible lower limit on deposit rates, ensuring the effectiveness of monetary policy. However, Bindseil (2020) and Broadbent (2016) highlight that the introduction of negative rates via CBDC would likely require the phasing out of physical cash, especially higher-value banknotes.

⁴ The ELB refers to the practical lower limit on nominal interest rates that CBs can set, which may be slightly below zero. This bound exists because setting rates substantially below zero risks triggering significant adverse behaviours, such as the widespread conversion of bank deposits into physical cash, thereby constraining monetary policy implementation (Swanson, 2018).

Through a New Keynesian model of Dynamic Stochastic General Equilibrium (DSGE), Xin and Jiang (2023a, 2023b) suggest that the adoption of an interest-bearing CBDC represents a promising solution to overcome the limitations associated with ZLB⁵ on bank deposit rates, particularly in the context of NIRP. This approach allows CBs to implement more expansionary monetary policies, overcoming this limitation. Consequently, there is a greater capacity to stimulate consumption, investment and production, as well as the expansion of bank credit, factors that contribute to a more sustained economic recovery. Xin and Jiang (2023a) show that the elimination of the ZLB enhances the effectiveness of NIRP transmission, promoting the stabilization of fluctuations in the real economy and accelerating the recovery process. In parallel, Xin and Jiang (2023b) indicate that CBDC-based negative rate policies are more effective in mitigating the adverse effects of uncertainty shocks, allowing for faster stabilization and a more resilient economic recovery.

In a complementary way, Barrdear and Kumhof (2022), using a DSGE model calibrated in the pre-2008 U.S. economy, demonstrate that the introduction of a remunerated CBDC could generate significant gains in macroeconomic and financial stability. In a counterfactual scenario in which a CBDC equivalent to 30% of GDP was issued to buy government debt, they estimate a reduction in real interest rates by about 60 basis points, stimulating investment and increasing production by up to 3% at steady state.

In addition, CBDC, by paying an interest rate lower than government bonds but higher than bank deposits, would enable the government to reduce its financing costs by approximately 1.5% of GDP, enabling a reduction in distortive taxes and encouraging economic activity (Barrdear & Kumhof, 2022). The model developed by Barrdear and Kumhof (2022) also predicts that CBDC would increase monetary efficiency by providing liquidity without bank spreads, approaching Friedman's rule⁶, and improve the payments system by mitigating financial frictions associated with bank intermediation. Lastly, the

⁵ The ZLB refers to the nominal lower limit, typically close to 0%, below which monetary authorities are unable to reduce the policy interest rate without introducing significant distortions. This constraint undermines the effectiveness of conventional monetary policy, particularly its capacity to stimulate the economy through further rate cuts in periods of recession or deflationary pressure (Fernandes & Mota, 2023).

⁶ As noted by Barrdear and Kumhof (2022), the Friedman rule (Friedman, 1969) posits that, when CBs can issue money at zero marginal cost, monetary policy should aim for a zero nominal interest rate to eliminate the opportunity cost of holding money. In modern monetary systems, however, where most money is endogenously created by commercial banks, the marginal cost of money creation reflects the spread between lending and deposit rates, which remains positive due to financial frictions and regulatory constraints. The issuance of a CBDC, created independently of the banking sector, allows the economy to circumvent part of these frictions, thereby moving closer to the optimal conditions.

authors' proposal includes an issuance mechanism that swaps CBDCs for eligible assets instead of deposits, preventing direct bank runs and protecting the stability of the financial system.

In the case of non-interest-bearing CBDCs, Bindseil and Panetta (2020) identify a critical limitation: a zero-interest CBDC with unfettered access would undermine the continuation of NIRP. As the authors explain, if CBDC, the economy's lowest-risk asset, offered a guaranteed return of zero, it would become impossible to maintain negative rates on other financial instruments, as rational investors would simply shift their resources to CBDC. This would create, in the same formal way, an ELB for the interest rates of the economy, thus compromising the transmission of monetary policy.

To address this issue, Bindseil and Panetta (2020) propose a two-tier remuneration system: the first tier with a non-negative interest rate and the second tier with less attractive and potentially negative rates. This hierarchical structure would simultaneously achieve four fundamental objectives: to provide CBDCs under favourable conditions for the daily use of households, to offer unrestricted access to CBDCs for all economic agents (including companies and institutional investors), to control the risk of excessive bank disintermediation, and to preserve the CB's ability to implement NIRP, when deemed necessary.

The QE was one of the instruments used by CBs to inject liquidity into the financial markets, with the aim of increasing the monetary base in the form of excess reserves to influence the reduction of interest rates (Fernandes & Mota, 2023). Thus, as CBDCs assert themselves as closer substitutes for traditional bank deposits, their presence could moderate the expansion of bank reserves and bank deposits, that typically results from QE operations. In a situation without CBDC, the initial impact of this instrument translates into an expansion of commercial banks' balance sheets. This is because the CB acquires securities, issuing reserves that are credited to the account of the selling bank, which, in turn, credits the account of the issuer of the security (Infante et al., 2022).

However, the introduction of a sovereign digital currency could change this dynamic, the CB can transfer the payment directly to the issuer, without the need for a financial intermediary or continue to credit the issuer's account with a commercial bank, and the issuer can then transfer these funds to a CBDC account or a commercial bank account, repay a loan or use them for consumption or investment (Infante et al., 2022).

In turn, Frascini et al. (2021) demonstrate that the introduction of a CBDC during a QE program can hinder the reversibility of this policy and change the transmission mechanisms of monetary policy. Banks could face a reduction in excess reserves if a significant portion of bank deposits are converted into CBDC deposits, limiting the ability to buy back assets when the CB attempts to normalize monetary policy. This process is compounded by the fact that depositors tend to show less flexibility in liquidity management compared to banks (Chiu & Hill, 2015), which makes it difficult to quickly reverse liquidity flows to the banking system. As a result, the effects of QE may become more persistent, potentially limiting the future effectiveness of this policy (Frascini et al., 2021).

A critical analysis of unconventional monetary policy mechanisms reveals that CBDCs may facilitate the implementation of helicopter money policies, a concept originally introduced by Milton Friedman, through direct digital distribution to individual citizen accounts, thereby addressing the implementation challenges that have historically hindered CBs' ability to deploy helicopter money policies effectively (Dyson & Hodgson, 2016; Yang & Zhou, 2022). While direct transfers to households are, in principle, feasible without a CBDC, the adoption of a CB-issued digital currency could substantially reduce administrative costs and enhance the speed, precision, and scalability of such operations (Dyson & Hodgson, 2016). Historical precedents, such as the distribution of budget surpluses in Hong Kong (2011) and Ontario, Canada (2000), demonstrate the viability of these transfers in the absence of CBDCs, though typically at the cost of greater administrative burden and operational limitations (Engert & Fung, 2017).

Within this context, CBDCs can offer a complementary instrument to QE measures through the implementation of a policy referred to as "helicopter money", with the aim of stimulating aggregate demand (Engert & Fung, 2017). By transferring newly created funds directly and unconditionally to households, helicopter money ensures a more equitable distribution than QE, which operates mainly through indirect wealth effects and disproportionately benefits asset holders with lower marginal propensities to consume (Dyson & Hodgson, 2016). Dyson and Hodgson (2016) emphasise that this direct provision of liquidity avoids increasing household indebtedness and effectively targets consumers with higher propensities to spend.

Employing a Narrow Bank model, Reis and Tenreyro (2022) argue that within a CBDC-based monetary system, helicopter money operations could attain greater operational

efficiency by enabling instantaneous and targeted monetary transfers, allowing for the direct crediting of beneficiary's digital accounts. Nevertheless, a key conclusion arising from their analysis indicates that, despite this enhanced operational capacity, CBs would continue to be constrained by their existing mandates, which do not grant them the authority to unilaterally execute or target such transfers. Rather, the involvement and approval of fiscal authorities remain necessary to provide direction for these operations. Thus, while CBDCs may facilitate the technical implementation of helicopter money, their deployment would still require close coordination with fiscal policy.

Thus, CBDCs stand out for allowing instantaneous, programmable and traceable transfers, at a reduced cost, facilitating more direct control over the economic impact. Therefore, while the existence of a CBDC is not a necessary condition for this type of intervention, its presence can facilitate practical implementation. It should be noted, however, that these operations are exceptional and, in practice, tend to remain of limited relevance in the broader conduct of monetary policy (Engert & Fung, 2017).

Within this paradigm, the supply of CBDCs would adjust endogenously to demand fluctuations, thereby enhancing operational efficiency. Despite these structural changes, the CB would maintain its core role as lender of last resort, preserving its ability to expand CBDC supply in times of systemic instability and thus provide emergency liquidity. Research suggests that CBDCs can strengthen monetary policy tools by improving the effectiveness of transmission mechanisms. The successful implementation of instruments like NIRP ultimately depends on public acceptance and the resilience of financial institutions, which may be particularly vulnerable during periods of economic downturn.

4.3. Monetary Policy Transmission

Monetary policy decisions influence a range of macroeconomic variables, primarily through adjustments in the interest rate, via a transmission process that unfolds across various segments of the financial system. Changes in official interest rates initially affect short-term money market rates, which are then transmitted to other interest rates in the economy, such as lending and deposit rates, thereby influencing the financing conditions faced by households and firms (ECB, n.d.-c). This mechanism constitutes a main channel through which CB decisions shape the consumption and investment behaviour of economic

agents (Fernandes & Mota, 2023). To frame the analysis, Table 2 outlines the principal transmission channels, detailing their operational mechanisms and macroeconomic effects.

Table 2. Summary of Monetary Policy Transmission Channels

Channel	Mechanism	Main Economic Effect
Interest Rate	Changes in the policy rate influence general interest rates across the economy.	Affects borrowing costs and returns on savings, thereby influencing consumption and investment decisions.
Bank Lending	The policy rate impacts banks' funding costs and balance sheet conditions.	Alters the availability and cost of credit, affecting credit-financed consumption and investment.
Exchange Rate	Monetary policy affects exchange rate dynamics through interest rate differentials.	Exchange rate appreciation or depreciation influences net exports and balance sheet positions in foreign currency.
Substitution	Changes in the interest rate affect decisions between present and future consumption, and consequently, savings decisions.	Increases (decreases) in the real interest rate may reduce (increase) present consumption and raise (lower) savings, while increasing (decreasing) future consumption.

Source: Author own's based on Das et al. (2023) and Fernandes and Mota (2023).

Given the key transmission channels outlined, it becomes clear how the introduction of a CBDC could modify or enhance these mechanisms. In particular, the impact of CBDCs on interest rates, credit provision, saving behaviour, and the exchange rate channel is crucial to understanding their potential contribution to the efficacy of monetary policy.

4.3.1. Domestic Channel Impact

This section examines the impact of CBDCs on the domestic transmission mechanisms of monetary policy, that is, the ways in which the introduction of CBDC may influence the domestic channels through which policy decisions affect the real economy. A distinction is made between interest-bearing and non-interest-bearing CBDCs, as their respective design features shape the transmission process in different ways.

4.3.1.1. Interest-bearing CBDC

The introduction of a CBDC, especially if interest-bearing, has the potential to significantly enhance a CB's control over short-term interest rates, which remain a primary

instrument of monetary policy. This direct influence over the interest rate channel, as a core transmission mechanism, may also have broader implications by affecting other channels, such as the bank lending channel and the substitution channel. Engert and Fung (2017) emphasise that the CB would retain the authority to determine the terms of both CBDC and bank reserves, thereby ensuring alignment between the respective interest rates to prevent arbitrage opportunities within the banking sector.

Moreover, Dong and Xiao (2024) refined the concept through their dual interest rate mechanism, whereby the spread between the CBDC remuneration rate and bank deposit rates function as an additional monetary policy tool. In this way, a CBDC may strengthen existing monetary policy frameworks by directly influencing the interest rate on digital currency, improving liquidity management, and enabling more effective implementation of measures such as NIRP or targeted monetary injections (Meaning et al., 2021).

Regarding long-term interest rates, the introduction of an interest-bearing CBDC could represent a substantial improvement in the transmission mechanism of monetary policy. At present, CBs exert influence over the yield curve primarily through the guidance of short-term rates. However, in environments where interest rates approach the ELB, the effectiveness of this mechanism becomes increasingly limited, as discussed in Section 4.2. Under such circumstances, the effectiveness of expectation-based transmission is severely limited, due to agents' preference for holding physical currency, which bears a zero nominal return (Bordo & Levin, 2017). An remunerated CBDC would allow this constraint to be lifted, restoring the full functionality of the transmission channel from short to long rates by more effectively anchoring economic agents' expectations, even in environments characterised by persistently low interest rates (Bordo & Levin, 2017).

In this context, Bordo and Levin (2017) argue that a CBDC would significantly reduce the need for CBs to resort to unconventional interventions in long-term sovereign debt markets, such as QE implemented following the 2008 financial crisis. Their proposal would thus imply a reconfiguration of the institutional boundaries between monetary policy and public debt management. Rather than acting directly on the long end of the yield curve, CBs would return their focus to controlling short-term rates as the main instrument to affect the term structure of interest rates, while fiscal authorities would be responsible for determining the maturity profile of sovereign debt, thereby restoring a more traditional separation between these two spheres of economic policy.

Beyond contributing to the effectiveness of transmission along the yield curve, an interest-bearing CBDC may also have structural effects on the functioning of the banking system and on how monetary policy instruments influence the behaviour of economic agents. By enabling CBs to set interest rates on CBDC holdings, this instrument assumes a more direct role in guiding consumption and investment decisions, as proposed by Syarifuddin and Bakhtiar (2022). The increased relative attractiveness of CBDC compared to traditional bank deposits would introduce competitive pressure on commercial banks, compelling them to adjust their deposit remuneration rates in order to prevent fund migration.

This dynamic would reinforce the interest rate channel by influencing bank deposit rates, while potentially transforming the lending channel, as a less stable funding base would alter the marginal cost of financing, especially when institutions rely on wholesale markets to cover liquidity shortfalls (Syarifuddin & Bakhtiar, 2022). Consequently, commercial banks may be forced to raise the interest rates offered on deposits as a means of retaining resources, resulting in higher credit costs and, consequently, a potential constraint on the supply of financing to the real economy.

However, as noted in Section 4.1, Lukonga (2023) warns of a significant limitation arising from the introduction of an interest-bearing CBDC, namely, the unpredictability of its demand. This uncertainty could weaken monetary policy transmission by reducing the CB's control over the money supply. Changes in money velocity may disrupt the conventional relationship between monetary aggregates and inflation targets, introducing instability into the policy process. Furthermore, significant deposit migration to CBDC could reduce the funding base of commercial banks, constrain their lending capacity and thereby limit the overall supply of credit to the economy (Lukonga, 2023).

In addition, in a negative interest rate environment, digital assets, including CBDCs themselves or deposit-based instruments, may incur nominal losses, encouraging economic agents to shift towards cash, which preserves a zero nominal return. Such a flight to physical money would undermine the effectiveness of monetary policy transmission by reinstating the ELB that was previously mitigated. To prevent this shift and preserve the integrity of the transmission mechanism, CBs may be compelled to adopt measures such as limiting convertibility between CBDC and cash or even restricting the supply of banknotes in circulation (Engert & Fung, 2017).

Recent theoretical contributions have explored how CBDCs may introduce entirely new dimensions to monetary policy transmission. Assenmacher et al. (2023) demonstrate that the introduction of a CBDC enables the CB to actively manage the liquidity premium (i.e., the additional value that agents attribute to assets that can be used for transactions) by endogenously adjusting the quantity of digital money in circulation. Unlike physical cash, a CBDC allows the CB to respond to liquidity shocks through an explicit rule governing its issuance in response to changes in transaction frictions or money demand.

This mechanism operates through two distinct transmission channels that influence the allocation between consumption and investment. First, the supply of CBDC directly affects consumption in decentralised markets⁷. When the CB increases CBDC supply, agents have greater access to transaction-facilitating assets, stimulating consumption in markets where cash-in-advance constraints are binding. Second, CBDC issuance affects bank funding conditions and thereby influences investment decisions (Assenmacher et al., 2023). Since CBDC and bank deposits function as substitutes in agents' portfolios, changes in CBDC supply alter the deposit base available to banks, impacting their capacity to extend credit and finance productive investment. Through these channels, the CB can separately influence both the medium of exchange function (via direct liquidity effects) and the store of value function (via relative returns and funding conditions) of money (Assenmacher et al., 2023).

The CB can thus stabilise the liquidity premium in response to shocks, such as a deterioration in the efficiency of bank deposit payments or a rise in agents' preference for liquid assets, by issuing or withdrawing CBDC. This adjustment capacity helps mitigate the effects of such shocks on consumption in the decentralised market and on financing conditions in the banking system, contributing to reduced volatility in output and inflation. Assenmacher et al. (2023) conclude that, although the introduction of a CBDC does not compromise the effectiveness of interest rate-based monetary policy, it constitutes an additional and autonomous tool to attenuate the effects of exogenous disturbances. This countercyclical functionality expands the set of instruments available to the monetary authority, enhancing its ability to simultaneously pursue price and financial stability objectives.

⁷ In the DSGE model developed by Assenmacher et al. (2023), the centralised market treats money as a store of value, with bank-intermediated finance subject to leverage constraints, while the decentralised market features bilateral, anonymous exchanges requiring liquid payment instruments such as bank deposits or CBDC.

A CBDC may also strengthen the transmission channels of monetary policy by promoting financial inclusion, an objective shared by several jurisdictions evaluating the adoption of this new form of fiat money. Mehrotra and Nadhanael (2016) show that in emerging Asian economies, higher levels of financial inclusion are associated with greater sensitivity of output and prices to interest rate changes, although part of this effect may stem from indirect impacts on traditionally excluded population segments.

In this context, a CBDC, particularly if interest-bearing, may enhance the effectiveness of monetary policy through expanding the transmission of interest rate changes to a broader set of economic agents, thereby influencing their intertemporal consumption and saving decisions (Adrian & Mancini-Griffoli, 2021). By facilitating access to formal financial instruments, namely through the generation of digital histories that contribute to more accurate credit risk assessment, CBDCs broaden the exposure of new consumers to benchmark rates, thereby intensifying the responsiveness of aggregate demand to interest rate fluctuations (Das et al., 2023).

In sum, the introduction of a remunerated CBDC, represents an addition to the conduct of monetary policy by reinforcing traditional transmission mechanisms, expanding the base of agents responsive to interest rate changes, and offering additional tools to mitigate economic shocks. While operational challenges and potential impacts on banking system stability do exist, many of these risks may be reduced and mitigated through the appropriate design of CBDCs by CBs, as will be discussed in the following sections. Thus, the CBDC emerges as a meaningful complement to conventional frameworks, enhancing the efficacy and reach of monetary policy.

4.3.1.2. Non-interest-bearing CBDC

The literature suggests that an unremunerated CBDC, by not bearing interest, does not directly respond to changes in the policy rate and therefore has a limited effect on the interest rate channel of the monetary policy transmission mechanism (Bindseil, 2020; Chucherd et al., 2018). In normal circumstances, its impact on the deposit behaviour of households and firms is minimal, as both continue to favour interest-bearing assets, such as savings accounts, term deposits, and bonds that provide positive returns.

However, in times of financial stress or when interest rates are negative, the relative attractiveness of CBDC may increase, particularly due to its safety and nominal stability, leading households to shift funds away from bank deposits (Chucherd et al., 2018). This can undermine banks' funding base and their ability to extend credit. In this context, the introduction of such a CBDC can indirectly influence the interest rate channel by intensifying competition in the deposit market and prompting shifts in household portfolio allocations, particularly during periods of financial stress or negative interest rates, potentially leading to implications for the overall effectiveness of monetary policy transmission (Das et al., 2023).

In line with this reasoning, Das et al. (2023) argue that a CBDC functioning as an alternative store of value places downward pressure on banks' net interest margins, thereby constraining their ability to retain deposits without responding to shifts in the policy rate. Consequently, banks may be compelled to adjust their deposit rates more rapidly, enhancing the responsiveness of the interest rate channel and facilitating a more direct pass-through of policy decisions to households and firms. This development aligns with the intertemporal consumption model proposed by Attanasio (1995), wherein changes in interest rates induce economic agents to revise their consumption and saving preferences over time. Specifically, higher real interest rates encourage a shift from present to future consumption, strengthening what is referred to as the substitution channel.

In particular, the substitution of deposits with a CBDC may increase banks' reliance on wholesale funding, which refers to non-deposit bank financing obtained from capital markets or other financial institutions, thereby heightening their sensitivity to fluctuations in the policy rate. As Das et al. (2023) explain, wholesale funding costs tend to exhibit greater responsiveness to changes in the CB's policy rate compared to retail deposits, which are relatively inelastic to interest rates. Furthermore, when banks depend more heavily on wholesale markets, changes in their balance sheets can have a more pronounced effect on overall funding costs, as uninsured wholesale funding is more reactive to variations in a bank's financial condition. During periods of policy tightening, this heightened sensitivity may lead banks to pass on rate increases more assertively to borrowers, thereby amplifying the effectiveness of the transmission mechanism.

Therefore, the introduction of a non-interest-bearing CBDC may, under certain conditions, amplify the sensitivity of the banking sector to policy rate changes, thereby exerting an indirect yet significant influence on the monetary transmission mechanism.

4.3.2. Exchange Rate Channel and International Dimension

The exchange rate channel is also an important part of the monetary policy transmission mechanism. It operates through the impact of interest rate changes on capital flows and exchange rates, thereby influencing net exports and aggregate demand (Das et al., 2023). According to the uncovered interest parity (UIP) condition, interest rate differentials between countries are expected to be offset by corresponding anticipated changes in exchange rates, assuming perfect capital mobility and risk neutrality (Froot & Thaler, 1990).

A non-interest-bearing CBDC is generally not expected to materially affect the exchange rate transmission mechanism, as it does not alter the fundamental risk–return trade-offs that shape cross-border capital allocation decisions (Das et al., 2023). In this case, the UIP condition remains essentially unchanged, as the CBDC does not introduce new incentives for interest rate arbitrage.

In this context, this section focuses on the implications of interest-bearing designs, especially when accessible to non-residents. Such arrangements can significantly influence exchange rate dynamics by introducing a new liquid, yield-bearing instrument. This, in turn, may foster capital market development and financial deepening, thereby enhancing the responsiveness of exchange rates to domestic monetary policy adjustments (Das et al., 2023). By facilitating non-resident access to the domestic digital currency, a CBDC may also contribute to greater capital account openness. Such a dynamic could undermine monetary policy autonomy, especially in economies operating under fixed or managed exchange rate regimes, where the scope for internal adjustments is already structurally constrained in favour of exchange rate stability (Das et al., 2023; Kim & Lee, 2008).

On the one hand, the adoption of a foreign CBDC domestically also raises the risk of currency substitution, as seen in highly dollarized or crypto-adopting economies, potentially weakening the effectiveness of domestic monetary policy (Das et al., 2023; Meaning et al., 2021). Addressing this risk, especially for smaller economies with exchange rate instability, may require regulatory measures, including restrictions on the use, holding, or transaction of foreign-issued CBDCs. On the other hand, by making the national currency more attractive as both a medium of exchange and a store of value, a CBDC can help reduce reliance on foreign currencies or crypto assets, partially restoring monetary sovereignty and thereby strengthening the effectiveness of monetary policy across all channels.

Moreover, the CBDC constitutes a potentially transformative vector of cross-border economic interdependencies. In a DSGE model, Minesso et al. (2022) demonstrate that CBDCs significantly intensify the international spillover effects of macroeconomic shocks, thereby strengthening transmission mechanisms across economies. This phenomenon arises from the emergence of a novel arbitrage condition that links domestic and foreign interest rates, exchange rate parity, and the remuneration of CBDCs. Consequently, exchange rate fluctuations become more pronounced, by approximately 20% in real terms following productivity shocks and international capital flows are considerably amplified. These dynamics exert asymmetric effects on non-issuing economies, which experience a decline in monetary policy autonomy, compelling their CBs to adopt markedly more reactive stances in response to inflationary pressures and output volatility.

Minesso et al. (2022) also demonstrates that the technical architecture of the CBDC is determinant for mitigating these effects, as CBDCs with flexible interest rate mechanisms (following Taylor rules) or marked-down interest rates⁸ significantly reduce international spillover effects (by approximately threefold), surpassing quantitative restrictions in efficacy. Such findings suggest the existence of potential competitive advantages for early implementers in the international monetary system, indicating that supranational coordination and meticulous consideration of the technical parameters of CBDCs will be crucial for managing their global impacts and preventing systemic imbalances.

In addition to these cross-border spillover effects, another dimension relates to the structural drivers of CBDC adoption. Auer et al. (2020) find that CBDC projects are more likely to emerge in economies with higher global integration, as measured by trade openness. Their research reveals a negative correlation between remittance flows and CBDC project advancement. This suggests that while cross-border payment efficiency is often cited as a CBDC benefit, it may not be the primary driver of actual implementation. The study does indicate, however, that countries exploring DLT tend to have greater dependence on remittance inflows, suggesting blockchain-based CBDCs may offer specific advantages for economies where remittances constitute a significant portion of financial flows.

⁸ The remuneration framework, characterised by a marked-down interest rate, entails CBDC retail holdings are remunerated at or near zero interest, while balances exceeding a certain threshold incur interest rates below prevailing market rates, potentially even negative. This mechanism is designed to mitigate the risk of bank disintermediation and to maintain the effectiveness of monetary policy implementation (Bindseil and Panetta, 2020).

5. CBDC Implementation Experiences

This chapter examines the implementation experiences of sovereign digital currencies across three pioneering nations: The Bahamas, Nigeria and Jamaica, all of which have fully deployed their CBDCs (Atlantic Council, n.d.). The introduction of these instruments has been primarily driven by persistent economic and structural constraints that hinder access to financial infrastructure and limit the efficiency of traditional payment systems. Despite facing high transaction costs and widespread financial exclusion⁹, these countries exhibit substantial digital connectivity and a discernible openness to technological innovation (Schumacher, 2024b). Beyond promoting financial inclusion and enhancing payment systems, each country implemented CBDCs to address unique national challenges:

- In The Bahamas, the “Sand Dollar” was introduced to address vulnerabilities arising from geographic fragmentation and natural disasters; despite high digital penetration, persistent reliance on cash and cheques required a digital solution to enhance payment efficiency, facilitate emergency transfers, and strengthen financial integrity (International Monetary Fund, 2024; Soderberg et al., 2022).
- Nigeria's “eNaira” emerged as a response to financial inclusion and, the proliferation of unregulated cryptocurrencies, addressing concerns over monetary sovereignty while providing a secure, official digital alternative (Komolafe, 2021; Okoduwa & Odiboh, n.d.; Olusegun et al., 2023).
- Jamaica developed “Jam-Dex” to address its oligopolistic banking sector, where two institutions control 60% of the market, while strengthening digital infrastructure in an economy vulnerable to climate shocks and limited financial development (Gail, 2022).

5.1. Design and Technical Framework

Table 3 presents the main features of the first CBDCs implemented, revealing notable structural similarities in their design. These sovereign digital currencies uniformly adopt a two-tier model, whereby CBs retain the exclusive right to issue the currency while distribution is delegated to authorised financial intermediaries. All maintain a fixed one-to-

⁹ Financial exclusion affects approximately 20% of the population in The Bahamas (International Monetary Fund, 2019, P.3), 17% in Jamaica (Gail, 2022), and 35,9% in Nigeria (Okoduwa & Odiboh, n.d).

one parity with their respective physical currencies and implement tiered know your customer (KYC) verification systems linked to progressive transaction limits.

Table 3. Technical Comparison of CBDC Frameworks

CBDC Feature	Sand Dollar (The Bahamas)	eNaira (Nigeria)	Jam-Dex (Jamaica)
Launch Year	2020	2021	2022
Remuneration	No	Currently under consideration for future deployment.	No
Technological Framework	Centralised digital ledger supporting both online and offline transactions	Hyperledger Fabric blockchain.	Centralised infrastructure integrated with the Bank of Jamaica (BoJ) RTGS system and digital wallets
Adoption Strategy	Gradual implementation through authorised financial institutions and government agencies	Promotion by local banks, user wallet downloads and funding, app upgrades to improve user experience.	Initial financial incentives for merchants and consumers.
Usage Mechanism	Digital wallets managed by authorised financial institutions, with options for physical payment cards for users without smartphones	P2P, person-to-business, diaspora remittances, person-to-government payments, social benefits, and potential use in lending, asset tokenisation.	Initially compatible with Lynk; expanded to include additional wallet providers and integration with government social programmes

Source: Author's own based on Schumacher (2024b).

In the implementation of the Sand Dollar in The Bahamas, the Central Bank of the Bahamas (CBOB) designed a DLT-based infrastructure in collaboration with the company NZIA Limited (CBOB, 2019). Although the system follows an hybrid model, the CBOB retains responsibility for issuing the digital currency, supervising account balances, and providing support in matters of identity verification and compliance (Schumacher, 2024b). The system also incorporates real-time transaction monitoring mechanisms and temporary circuit breakers, designed to prevent systemic failures or bank-run dynamics (CBOB, 2019). To mitigate potential adverse effects on financial stability, the CBOB implemented a tiered access system with progressive balance and transaction limits based on KYC requirements, ranging from B\$500 for low-risk users to B\$1,000,000 for corporate entities (Schumacher, 2024b).

The eNaira of Nigeria adopts a structure also based on blockchain with account-based recording, allowing for transaction traceability (Schumacher, 2024b). Its architecture, implemented by BITT Inc. using the Hyperledger Fabric platform, operates in two distinct layers, enabling interaction between wholesale clients (such as banks) and retail clients (merchants and individuals) (Ree, 2023). This design is complemented by a tiered KYC identity verification system that limits transactions and wallet balances for retail users. The equivalence to the physical currency facilitates public acceptance and strengthens the ability to monitor suspicious transactions. However, the lack of interest payments on this digital currency diminishes its appeal compared to traditional bank deposits (Nwosu et al., 2023).

According to Obiora (2023), this operational framework raises concerns about potential banking disintermediation, with implications for deposit mobilisation and economic financing. Functional aspects of the eNaira include programmability capabilities, which allow for the establishment of specific usage parameters, such as restricting spending to locations or items, especially useful for the implementation of targeted social programmes. In 2023, this technology have an update to incorporated Near Field Communication (NFC) technology, facilitating contactless payments between mobile devices and payment terminals (Schumacher, 2024b). The infrastructure has demonstrated resilience, with continuous, fault-free operation, yet faces challenges such as limited app functionalities, poor user experience, and restrictions for new users without a Bank Verification Number (BVN), along with reliance on mobile data access, which limits its relevance for certain segments of the population (Obiora, 2023; Schumacher, 2024b).

Meanwhile, the JAM-DEX was implemented as a centralised system, using an architecture integrated with the BoJ's RTGS system. This technological choice reflects a pragmatic approach, prioritising compatibility with existing infrastructure and operational efficiency (Schumacher, 2024b). The decision to opt for a non-blockchain solution further highlights the BoJ's focus on utilising a technology that seamlessly interfaces with the country's payment systems, without the complexities or challenges often associated with blockchain (Haynes, 2020). In addition to this thoughtful integration, security is ensured through multiple protection layers, such as encryption, digital signatures, and multi-factor authentication, all of which provide a robust framework while still enabling authorities to track payments for AML and CFT compliance.

5.2. Adoption and Policy Implications

The experience of implementing this sovereign digital currency in the three nations was short of expectations, with low adoption despite incentive programs designed to promote its uptake. Rolle (2022) argues that the adoption of the Sand Dollar remains relatively low, where everyday usage remains limited, particularly in contexts where traditional payment methods continue to dominate; reflecting a broader trend observed in other CBDC initiatives. Nevertheless, since its inception, the Sand Dollar has grown to approximately 2.6 million units in circulation, representing only about 0.09% of the country's total money supply (CBOB, 2024; 2025).

According to the JAM-DEX adoption indicators, the results remain significantly below the BoJ's initial expectations. Despite the government's offer of a J\$2,500 JAM-DEX incentive to the first 100,000 registrants via the Lynk app, only 36,000 users had enrolled by February 2023 (Observer, 2022; Patterson, 2023). As of March 2025, the total value of banknotes and coins in circulation was approximately J\$270 million, while the value of JAM-DEX in circulation was limited to only J\$258,452, representing a mere 0.096% of the country's overall money supply¹⁰, far below to the target of replacing 5% of physical cash annually (Gail, 2022). According to Dowd (2024), the failure to achieve substantial adoption of JAM-DEX stems from a structural disconnect with the underlying causes of financial exclusion, such as high banking fees, the prevalence of cash usage, the lack of documentation to meet KYC and AML requirements, and widespread distrust in authorities.

Table 4 provides a comparative overview of the monetary policy strategies and instruments adopted by the three countries under consideration. The differences observed reflect each jurisdiction's specific economic context, including their respective vulnerabilities to external shocks and developmental priorities. Each CB pursues a distinct approach to achieving monetary stability, as evidenced by the selection of primary instruments: Jamaica prioritises the policy interest rate, Nigeria relies predominantly on OMO, and The Bahamas employs a combination of reserve requirements and selective credit controls. This comparative perspective serves to contextualise the institutional and strategic diversity that may influence how CBDCs interact with, or potentially transform, existing monetary policy frameworks in the future.

¹⁰ Bank of Jamaica. (2025). *Balance sheet as at 26 March 2025*. <https://boj.org.jm/wp-content/uploads/2025/04/Balance-Sheet-Post-26-March-2025.pdf>

Table 4. Comparative Framework of CB Monetary Policy

Aspects	Bank of Jamaica (BoJ)	CB of Nigeria (CBN)	CB of The Bahamas (CBOB)
Main Objectives	Price stability via medium-term inflation target of 4.0%-6.0%	• Price stability and Sustainable growth • Full employment • Stable interest and exchange rates	• Fixed parity with US dollar (since 1973) • Monetary stability • Economic development
Operational Targets	Inflation rate within the target band	Reserve Money	Maintain external reserves at minimum 50% of currency in circulation and demand liabilities
Primary Instrument	Monetary policy interest rate	OMOs	• Reserve requirements • Bank discounts rate • Selective credit
Secondary Instrument	• OMOs • Reserve requirements • Interest rate corridor	• Reserve requirements • Discount window • Moral Suasion • Foreign exchange sales • Standing Facility	• Moral suasion • Interest rate controls • Market operations (limited)

Source: Author's own based on BoJ (2021); CBOB (n.d) and CBN (n.d-a, n.d-b).

Despite the divergence in monetary policy instruments and operational frameworks, the three jurisdictions under study each opted for a non-interest-bearing CBDC, designed solely as a payment instrument rather than a store of value. According to the literature review, these non-interest-bearing CBDC accounts would not substantially alter the effectiveness of monetary policy if benchmark interest rates remained clearly positive, functioning merely as an autonomous factor on the CB's balance sheet. However, such a setup would become relevant in negative interest rate scenarios, as depositors might prefer to hold balances in CBDC with zero holding costs, potentially posing a challenge to the transmission of monetary policy (Beniak, 2019).

In Nigeria, the eNaira was initially launched without account remuneration. However, its low adoption prompted a reassessment of this design, highlighting the potential appeal of interest-bearing digital deposits. From a monetary policy perspective, introducing a

remunerated eNaira would broaden the CBN policy toolkit, as the remuneration rate could operate as an additional channel for influencing savings and consumption decisions. Nwosu et al. (2023) emphasise that the rate set by the CBN would act as a minimum benchmark for commercial banks' deposit rates. To prevent banking disintermediation, Ozili (2023) proposes a calibrated approach, maintaining eNaira remuneration at a level below the rates practised in the conventional banking market, thus preserving the financial system's balance and its intermediation capacity.

Furthermore, Akintola and Question (2023) observe that changes to the monetary policy rate are swiftly transmitted to public debt instruments in Nigeria, especially long-term ones. This suggests that eNaira remuneration may influence the demand for government securities and the yield curve, requiring close monitoring to avoid adverse effects on liquidity and financial stability. Ree (2023) further underscores the importance of align eNaira expansion with exchange rate adjustments and robust regulation to ensure the inclusion of unbanked and digitally excluded populations.

One of the common objectives across the jurisdictions under analysis is financial inclusion, which may have implications for the transmission of monetary policy. Wright et al. (2022) argues that the degree of banking penetration directly affects the ability to control inflation through conventional monetary policy instruments. This approach aligns with Mehrotra and Nadhanael (2016), who claim that financial inclusion enhances monetary policy transmission, particularly in geographically challenging regions. However, Rahming (2021) cautions that such effectiveness also depends on overcoming structural barriers, including financial literacy and equitable access to services.

The comparative experiences reveal that the success of a CBDC depends on transversal factors: a clear legal framework, such as that provided by the CB Act in Nigeria; gradual implementation, allowing for the identification and correction of initial shortcomings; and specific governance, distinct from the management of physical currency, that addresses the technological and operational challenges inherent in the digital environment (Obiora, 2023). Public trust, institutional involvement, and technological infrastructure are crucial elements that condition the efficacy of these innovations. These national strategies reveal varying degrees of structural response to the limitations imposed by specific economic contexts, offering valuable lessons for other EMEs considering the implementation of digital currencies as an extension of their monetary policy tool.

6. Institutional Comparative Analysis

The monetary policy frameworks of the ECB and the FED differ in institutional mandates, objectives, and tools. This chapter provides a comparative analysis of their policy implementation, crisis management strategies, and implications for economic stability. While many CBs explore CBDCs with diverse motivations, this study focuses on the specific initiatives of the ECB and the FED to contextualise their approaches within the broader monetary policy landscape.

6.1. Institutional Characteristics

There are important institutional differences between the U.S. and the EA in terms of how supervisory and regulatory tasks are carried out, as well as the CB's function as a lender of last resort. Any assessment of the monetary policy approach must consider that the U.S. is a Federal system, in which the FED serves as the monetary authority of a single sovereign nation (FED, 2021). In contrast, the EA is an economic union made up of several sovereign states, where the ECB functions as a supranational institution responsible for setting and overseeing monetary policy across its member countries (Scheller, 2006).

Monetary policy decisions within the ECB are taken by the Governing Council, which is composed of the six members of the Executive Board and the governors of the national CBs of the EA (ECB, 2024b). The Council regularly assesses economic, monetary, and financial developments before determining the appropriate policy stance, while the implementation of these decisions is carried out by the national CBs. In the FED System, monetary policy is primarily conducted by the Federal Open Market Committee (FOMC), which comprises the seven members of the Board of Governors of the FED System, the President of the FED Bank of New York (as a permanent member), and four of the remaining eleven regional FED Bank presidents (FED, 2025). The Board supervises the functioning of the FED System as a whole and contributes to monetary policy decisions, drawing upon economic insights gathered by the Reserve Banks across the country (FED, 2025). The FOMC is specifically responsible for decisions regarding OMOs, which are the FED's main tool for implementing monetary policy (FED, 2021).

A fundamental distinction lies in the objectives of monetary policy. The ECB pursues a primary objective of maintaining price stability over the medium term, aiming to keep

inflation low, stable, and predictable, aiming for a 2% target, as measured by the Harmonised Index of Consumer Prices (HICP) (ECB, n.d.-d). In contrast, the FED operates under a dual mandate, there are the promotion of maximum employment and price stability (Mankiw, 2020). Its long-term inflation target is likewise set at 2%, as measured by the annual change in the Personal Consumption Expenditures (PCE) Price Index. Furthermore, a third objective (moderate long-term interest rates) is frequently regarded as a natural outcome of stable prices.

When analysing the recent actions of the FED and the ECB (see Appendix 1 and Appendix 2 for detailed analysis), a substantial difference in their approaches adopted from the 2008 financial crisis to the recent pandemic crisis becomes evident. The ECB was the first to respond, acting on August 2007 after BNP Paribas suspended redemptions from three of its funds exposed to the U.S. subprime market. These moves triggered strains in the interbank market, as banks, lacking clear information on potential losses, became hesitant to lend to each other, leading to a spike in interest rates and increased volatility. To stabilise the system, the ECB acted as a lender of last resort, providing significant liquidity to keep the Euro Overnight Index Average (EONIA)¹¹ close to its reference rate. However, it kept its main refinancing rate at 4% until July 2008, when it raised it to 4.25%, failing to anticipate the full scale of the crisis (Mota, 2023).

The ECB's initial response, while crucial to stabilising financial markets, was marked by a significant delay in lowering interest rates, which only occurred in October 2008, more than a year after the crisis began. This hesitation, combined with premature rate hikes in 2011, when the financial situation remained fragile, stood in stark contrast to the consistently accommodative stance of the FED, which included aggressive rate cuts and the early use of unconventional measures such as QE to anchor expectations and restore confidence among economic agents (Mota, 2023). This cautious approach can be partly attributed to the ECB's strict focus on maintaining price stability, as well as to institutional constraints. These include, for example, the prohibition of direct monetisation of public deficits and political sensitivities within the eurozone (Mota, 2023).

¹¹ Until 2019, EONIA was the euro money market benchmark interest rate for the overnight term. It is an effective interest rate calculated as the weighted average of all unsecured overnight lending transactions on the euro interbank market initiated in the euro area by contributing banks. This rate has been replaced by the Euro Short Term Rate (€STR), essentially changing the methodology for calculating the overnight indicator (Mota, 2023).

By learning from the late response to the 2008 global financial crisis, the ECB applied all unconventional monetary policy instruments more quickly and on an appropriate scale during the COVID-19 crisis, albeit hesitantly and cautiously (Mota, 2023). This prudence resulted from the need to manage the heterogeneity of the economies of the eurozone member countries, whose recovery showed different paces. In addition to the swift implementation of the Pandemic Emergency Purchase Programme (PEPP), the ECB sought to ensure clear and consistent communication to minimise uncertainty in the markets and support financial stability (Fayed, 2024). At the same time, it maintained an accommodative monetary policy for a prolonged period, avoiding premature tightening that could jeopardize the economic recovery of the most vulnerable states.

In contrast, the FED, under Bernanke's leadership, responded more forcefully between September 2007 and December 2008, intervening directly to rescue Bear Stearns in March 2008 and swiftly recognising the systemic risks and potential for recession (Mota, 2023). The FED demonstrated a significantly more proactive stance, distinguished by the speed with which it resorted to unconventional instruments during the financial crisis. Measures such as QE and the use of forward guidance helped anchor expectations and bolster confidence among economic agents. This early action reflected a strategy focused on the preventive management of systemic risk, aiming to contain the recessive dynamics even before inflationary pressures fully materialised (Ligthart et al., 2016). In the post-pandemic period, the FED responded to rising inflationary pressures by implementing a sharp increase in interest rates and initiating a process of quantitative tightening to absorb the excessive liquidity expansion in the financial system (Fayed, 2024).

Overall, we observe that while the FED initially responded to both the 2008 financial crisis and the COVID-19 pandemic with decisive and expansionary measures, it stood out in the post-pandemic period for its swift adoption of contractionary policies aimed at curbing inflation, including sharp interest rate hikes and quantitative tightening. In contrast, the ECB showed greater concern with avoiding asymmetric shocks and dysfunctions in the sovereign bond market, which aligns with the institutional differences identified.

6.2. ECB Project: The Digital Euro

The ECB and the European Commission justify the creation of a digital euro as necessary to ensure the continued role of public money as a fundamental common good,

while also safeguarding the monetary sovereignty and strategic autonomy of the European Union (EU) in an increasingly digitalised context (Cipollone, 2024). In this context, the digital euro will be available throughout the EA and seeks to provide Europeans with an additional secure and reliable means of payment, both physical and digital, facilitating online, P2P, and business-to-business transactions (Lagarde, 2025; Urbinati et al., 2021).

In a monetary union such as the European one, the issuance of a CBDC would offer broader benefits compared to a nation with its own national currency (Lane, 2025). On the one hand, it would enable the creation of a unified and efficient payment system by addressing existing inefficiencies that increase cross-border transaction costs and limit both competition and innovation in the sector (Cipollone, 2025b; Lane, 2025). In the realm of retail payments, a digital euro would present an opportunity to strengthen Europe's strategic autonomy by reducing its reliance on non-European private payment infrastructures (e.g. VISA or Mastercard) and fostering the emergence of a more competitive and resilient European private payment solution (Cipollone, 2025b; Lane, 2025). Regarding wholesale payments, the adoption of new technologies holds the potential to avoid the type of structural inefficiencies that have historically affected Europe's retail payment sector (Cipollone, 2025b).

The digital euro would function as a digital form of the euro currency, issued directly by the ECB but distributed to citizens through PSPs, such as banks and other financial institutions, as the ECB plans to deploy it using a hybrid distribution model¹² (Barton et al., 2025). The European Commission (2023) emphasises that the technical design of the digital euro must be broadly accessible and usable by the general public. It must ensure that financially excluded individuals, people with disabilities (in accordance with the accessibility requirements set out in Annex I of Directive (EU) 2019/882 of the European Accessibility Act), individuals with functional limitations, as well as those with limited digital skills and elderly people, can benefit from its use.

In line with the conceptual distinction outlined in Section 3.2. between account-based and token-based models, the digital euro is expected to incorporate elements of both, to ensure universal accessibility. Thus, the ECB (n.d.-a) notes that individuals with a bank

¹²As previously discussed, a hybrid CBDC model combines features of both direct and indirect systems, allowing users to maintain a direct claim on the CB, while PSP facilitate users' interactions with the CB's infrastructure, including account management and transaction execution (Auer & Böhme, 2020).

account linked to their digital euro wallet would benefit from a simplified onboarding process, efficient transfer of funds, and automatic balance management between the wallet and the associated account (reverse waterfall, which will be discussed below), characteristics consistent with the account-based model. At the same time, individuals without a bank account but with access to a digital device would be able to use a wallet or application, likely provided by the ECB. Additionally, to support the objective of inclusion, the digital euro would also be made available to individuals without either a bank account or digital device through payment cards issued and recharged by public agencies, such as post offices, reflecting elements of the token-based model (ECB, n.d.-a).

Moreover, the ECB is currently evaluating a range of technical architectures for the digital euro, encompassing both centralised and decentralised solutions, including DLT, which were analysed in Section 3.5 (ECB, 2024a). In parallel with its technological exploration, the ECB reveals key aspects of the digital currency design: setting a holding limit, absence of remuneration, and offline availability (ECB, 2024; Bindseil et al., 2024). As previously discussed, the introduction of a CBDC raises concerns about financial stability and the transmission of monetary policy. To mitigate these risks, the ECB plans to limit the amount of digital euros that individuals can hold (Bindseil et al., 2024). This measure reduces the risk of excessive adoption, which could undermine interest rate transmission and liquidity management.

Furthermore, the digital euro being non-interest bearing would reduce the incentive to hold large balances, reinforcing its intended use in day-to-day transactions, rather than as a store of value (Bindseil et al., 2024). Nevertheless, the ECB emphasises that, while no remuneration is foreseen at the time of issuance, it cannot be ruled out that in the future, should monetary policy objectives require it, the digital euro could bear interest. Such a decision would remain under the exclusive competence of the ECB, in line with its primary mandate of maintaining price stability (Lagarde, 2023).

In addition to the holding limits, the digital euro design could incorporate mechanisms for more flexible liquidity management, such as the “waterfall” and “reverse waterfall” approaches (ECB, 2022a; Brühl, 2025). These mechanisms ensure that transactions exceeding the available digital euro balance can still be completed by automatically drawing on linked commercial bank deposits, thereby mitigating the risk of failed payments while preserving a stable deposit base. The “waterfall” mechanism ensures

that digital euro inflows exceeding the established threshold are automatically transferred to the associated commercial account. Conversely, if the digital euro balance is insufficient for a transaction, additional euros are transferred from the linked bank account to the digital euro account to complete the payment, a process known as “reverse waterfall” (Brühl, 2025).

This sovereign digital currency in development aims to be available for both online and offline¹³ payments. Users should have the right to convert their holdings between these two forms at par value. Moreover, prior to a proximity payment, both the payer and the payee must be informed whether the transaction will be processed online or offline (European Commission, 2023). This modality also entails important privacy implications. In the case of the offline digital euro, privacy protections are expected to be stronger than those in online transactions. Low-value payments would be treated similarly to cash, with no data shared with PSPs or the Eurosystem, except as required for compliance with AML and CFT regulations (Daman, 2024). Thus, offline functionality enables private and resilient P2P electronic payments in crisis situations.

In summary, the digital euro project represents a strategic initiative by the ECB to preserve the role of public money in the digital age, enhance the efficiency and resilience of the European payment’s ecosystem, and promote financial inclusion. By combining technological innovation with safeguards for privacy and accessibility, the ECB aims to design a functional digital currency that strengthens monetary sovereignty, supports Europe’s strategic autonomy, and contributes to the stability of the EA’s financial system.

6.3. FED Banks Projects

To date, the FED System has not reached an official decision regarding the issuance of a digital dollar, with the matter currently under deliberation in the U.S. Senate (Atlantic Council, n.d.). According to the Atlantic Council (n.d.), the FED is classified as being in an "other situation" regarding CBDC development, as a January 2025 executive order issued by the Trump administration mandated the suspension of all ongoing work related to CBDCs (Atlantic Council, n.d.). However, it is well established that the FED will not proceed without

¹³ This functionality will rely on secure elements, such as hardware chips integrated into user’s mobile devices, providing a level of privacy like that of cash.

explicit support from both the executive branch and Congress through authorising legislation (FED, 2022).

However, efforts related to wholesale CBDCs continue, as demonstrated by the ongoing participation of the FED Bank of New York in cross-border research projects such as *Project Cedar x Ubin+* and *Project Agorá* (Atlantic Council, n.d.). Nevertheless, this dissertation focuses specifically on the retail dimension of CBDC design and its implications for monetary policy, with particular attention given to Project Hamilton. This initiative, conducted jointly by the FED Bank of Boston and the Massachusetts Institute of Technology (MIT) Digital Currency Initiative, has been engaged in research on potential CBDC issuance since 2020, exploring the technological feasibility of a retail CBDC for the U.S. economy (FED Bank of Boston & MIT, 2023). The first phase of Project Hamilton focused on the design of a central transaction processor capable of meeting stringent requirements for speed, throughput, and fault tolerance, while also providing a flexible platform to support collaboration and further research.

Building on the technological foundations established in its first phase, Project Hamilton advances beyond the CBDC design frameworks commonly presented in the literature, known as the account-based versus token-based dichotomy discussed in Section 3.2. Lovejoy et al. (2022) advocates for an approach centred on the engineering decisions that directly shape the functionality and resilience of a CBDC. Specifically, the project identifies four critical technical dimensions: (i) the trust and threat model, which defines the risks the system must mitigate and who is responsible for doing so; (ii) the transaction format (i.e., the structure through which payment data are represented, processed, and validated); (iii) fault tolerance mechanisms, which ensure service continuity in the event of disruptions or attacks; and (iv) scalability strategies, which are essential to guarantee efficiency under high transaction volumes (Lovejoy et al., 2022).

Accordingly, the modular architecture enables the separation of these components, facilitating parallel transaction processing, independent node replication, and adaptability to various institutional or technological configurations (Lovejoy et al., 2022). This modularity supports, for instance, both intermediated and self-custody models, eliminating single points of failure and providing geographic fault tolerance (as categorised in Section 3.4 into direct, indirect, or hybrid models). From a privacy perspective, the system avoids the centralised

storage of user identities or balances, offering varying degrees of anonymity depending on regulatory requirements.

Technologically, the project relies on classical distributed computing algorithms rather than blockchain or DLT, which were analysed in Section 3.5. This approach enables a high-performance and flexible modular architecture. This design not only allows for the separation of functions, such as validation, storage, and auditing, but also supports parallel transaction processing, independent module replication, and adaptation to different institutional frameworks (Lovejoy et al., 2022). By avoiding the centralised storage of identity or balance data, the system provides configurable privacy options without compromising regulatory compliance. Moreover, it accommodates both self-custody wallets and intermediated solutions, thereby enhancing geographic resilience.

In this context, the Phase 1 of the project demonstrated the capability to settle 99% of transactions in under two seconds, with a processing capacity of up to 1.7 million transactions per second. These findings also highlighted the scalability benefits of modular designs, which allowed for parallel transaction processing and independent replication, enhancing both speed and fault tolerance. Moreover, they demonstrated that achieving the desired performance did not depend on a distributed ledger across multiple jurisdictions (FED Bank of Boston & MIT, 2023).

The second phase explored alternative technical configurations, evaluating critical components such as cryptographic architectures for privacy, auditability mechanisms, smart contract programmability, and offline payment solutions (FED Bank of Boston & MIT, 2023). This phase resulted in the development of the OpenCBDC codebase, providing an unbiased resource for the global financial community to assess different technical options for a potential CBDC (Lindsay, 2022).

In conclusion, while the FED has not committed to issuing a digital dollar, Project Hamilton has significantly advanced the technical understanding of high-performance retail CBDC systems. Its emphasis on scalability, resilience and privacy, independent of DLT, offers a neutral and adaptable foundation for future design choices. By publishing the OpenCBDC codebase, the project also contributes to broader international efforts by enabling further research and cross-border collaboration.

7. Implications and Findings

An examination of the approaches adopted by two of the world's leading monetary institutions, the ECB and the FED, reveals a marked divergence in their CBDC strategies, shaped by distinct institutional, economic, and political conditions that influence how each CB evaluates the role of sovereign digital currencies in its policy framework.

The FED maintains a cautious stance on the issuance of a “digital dollar”, largely due to the U.S. dollar's dominant position in international markets. The U.S. dollar's dominance is underpinned by the supply of Treasuries, deep and liquid markets, and longstanding macroeconomic stability, reinforcing its global role despite innovations like foreign-issued CBDCs (Flemming & Judson, 2024). In addition, the strength of the U.S. financial system and efficient private-sector payment solutions further consolidate this position (Anthony & Michel, 2023). As a result, U.S. authorities do not currently regard the introduction of a CBDC as an urgent requirement to preserve the dollar's global standing.

In contrast, the Eurosystem has adopted a proactive stance in advancing the development of the digital euro, recognising the imperative to adapt to the accelerating digitalisation of payment systems and to safeguard monetary sovereignty in an increasingly technology-driven environment. A key structural factor underpinning this approach is the fragmentation of payment systems in the EA, particularly in the digital sphere, where national solutions prevail over pan-European alternatives, creating frictions in cross-border transactions and fostering reliance on non-European payment providers (Cipollone, 2025b). Consequently, the digital euro has considerable potential to strengthen integration within the EA and support the broader pan-European objective of payment integration by providing a shared digital infrastructure that lowers barriers for payment service providers, reduces cross-border transaction costs, and fosters the widespread adoption of innovative payment solutions (Cipollone, 2025b; ECB, 2020; Lane, 2025).

This divergence is further accentuated by differing attitudes towards private sector innovations, particularly stablecoins. Waller (2025) argues that such stablecoins may help maintain, and potentially expand, the international role of the U.S. dollar, especially in economies characterised by high inflation or limited access to physical cash and U.S.-denominated financial services. Consequently, the current U.S. administration's policy direction, which actively supports crypto-assets and dollar-backed stablecoins, presents

significant challenges for Europe, as highlighted by Cipollone (2025a). This dynamic not only raises financial stability concerns but may also undermine Europe's strategic economic autonomy, reinforcing the rationale for developing a European CBDC.

It is within this framework that a thorough analysis of the implications for the conduct of monetary policy regarding CBDC issuance becomes essential. As examined in Chapter 5 and Section 6.2, most jurisdictions, such as the EA, have opted for a non-interest-bearing CBDC design. Nevertheless, in certain cases, such as that of the CBN, the introduction of an interest-bearing eNaira is under consideration. For this reason, the analysis compares both design approaches to highlight their implications for the efficacy of monetary policy.

As analysed in Chapter 4, the non-interest-bearing nature of the proposed digital currencies, intended to replicate the characteristics of physical cash, means that the issuance of such CBDCs could have important implications for monetary policy. The extent and nature of these implications, however, will largely depend on the specific design features of the CBDCs. It is important to recognise that under normal economic conditions, the impact of a CBDC on monetary policy transmission may be limited. Nonetheless, its effects could become considerably more significant in environments characterised by persistently low interest rates or heightened financial market stress (Das et al., 2023).

Although the use of cash as a means of payment is declining due to the increasing digitalisation of payment systems, its function as a store of value remains significant, particularly during periods of uncertainty. In this context, the introduction of a non-remunerated CBDC could reinforce the ELB in a manner similar to cash, by facilitating the shift of bank deposits to CBDC holdings in times of financial stress, especially if quantitative limits are not imposed (Das et al., 2023). Unlike physical cash, however, CBDCs do not incur storage costs, which may encourage larger precautionary shifts and thereby increase the risk of bank runs and financial instability.

Nonetheless, within a well-calibrated institutional framework, such as the implementation of holding limits, a non-remunerated CBDC could still contribute to enhancing the transmission mechanism of monetary policy, as illustrated in one of our case studies, namely the digital euro (Section 6.2). By incentivising competition among commercial banks for deposit funding, it could increase the sensitivity of deposit rates to changes in the policy rate. Furthermore, it may render wholesale funding markets more responsive to CB decisions, thereby strengthening the interest rate channel (Section 4.3.1.2)

(Das et al., 2023). In addition, by promoting financial inclusion, a CBDC may allow monetary policy to reach previously unbanked or underbanked segments of the population, broadening its overall effectiveness (Section 4.3.1.1). These mechanisms would contribute to a more robust and inclusive transmission of monetary policy to the real economy, while preserving the essential functions of physical cash (universal access to a risk-free means of payment).

In the case of the digital euro project, a strategically designed framework has been proposed to mitigate risks to financial stability. In particular, the introduction of holding limits, still under discussion regarding their exact thresholds, could prevent large-scale substitution of bank deposits by CBDCs (Kunaratskul et al., 2024). This is of particular importance, as a widespread shift to CBDCs could reduce commercial banks' reserves at the CB. As outlined in Section 4.1, under a corridor system (i.e., with scarce reserves), such a reduction could result in upward pressure on market interest rates. However, under a floor system (i.e., with abundant reserves), as currently adopted by both the ECB and the FED, such an outcome is less likely, unless the substitution effect becomes particularly significant.

Beyond its role as a means of payment, a CBDC can be designed to bear interest, serving as a more sophisticated and comprehensive monetary policy instrument (Barrdear & Kumhof, 2022; Bindseil, 2020). As discussed in Section 4.3.2, a remunerated CBDC can complement conventional tools while helping to mitigate the risks of capital flight and currency substitution (Das et al., 2023). In non-crisis situations, the interest rate applied to the CBDC would typically be indexed to the CB's reference rate. If this rate were higher than that offered on commercial bank deposits, it could generate direct competition for retail funding. Such competition would place additional pressure on commercial banks, prompting adjustments not only to deposit rates but also to lending rates and, consequently, to the overall supply of credit. This process could, in turn, strengthen the effectiveness of monetary policy transmission through multiple channels, most notably the interest rate channel and the bank lending channel, as analysed in Sections 4.1 and 4.3.1 (Das et al., 2023).

In this approach, not only positive interest rates can be applied, but also negative interest rates, which can increase the capacity of monetary policy to intervene to stimulate the economy in a crisis. This capacity may be constrained by incentives to move into non-interest-bearing assets, such as cash. However, Das et al. (2023) argued that even with the coexistence of a CBDC with a negative interest rate and physical cash, the difficulties in obtaining and holding large amounts of cash could still allow for some flexibility.

By enabling direct control over the CBDC interest rate, this approach could reduce reliance on unconventional tools, such as QE and forward guidance, which, although widely used after the global financial crisis, raise concerns about their effects (Bordo & Levin, 2019). For example, QE, by expanding the CB's balance sheet, can generate side effects (e.g. speculative bubbles, currency wars, inequalities in income distribution), while forward guidance depends on the CB's credibility, coherence in communication, and internal consistency (Fernandes & Mota, 2021). As Bordo and Levin (2019) note, this “digital cash” would provide a costless means of payment, as well as a secure and stable store of value. This would facilitate the application of negative interest rates, allowing the CB to bypass the ELB and conduct monetary policy in a more systematic, transparent, and effective manner, both in normal times and during severe economic shocks, as discussed in section 4.2.

While the literature suggests that an interest-bearing CBDC brings benefits to monetary policy through more direct transfers adjusted to macroeconomic conditions, the WB (2021) warns that its implementation can have significant political and social consequences. For example, while negative interest rates in a CBDC do not necessarily imply negative long-term interest rates, they would lead to a general reduction in rates, which would have effects on pension funds and other long-term capital markets (WB, 2021). In addition, it could hurt risk-averse savers, as low-risk savings options would have very low or even negative rates, if they would still prefer to keep deposits in banks for safety rather than invest directly in companies with a higher risk of loss. The application of negative interest rates could be seen as a form of expropriation or taxation by the CB, raising questions about the legitimacy and duration of this “financial repression” (WB, 2021). This could require changes in CB's roles and mandates, even before deciding to move forward with a remunerated CBDC, which would have profound implications for the nature of the monetary authority.

In the U.S., where CBDC issuance remains politically contentious, the potential effects of a digital dollar would likely be primarily technological (Anthony & Michel, 2023). By contrast, in economies with weaker institutional frameworks and fragile financial infrastructures, such as the jurisdiction studied in the Chapter 5, CBDC issuance may have more significant effects, particularly in contexts characterised by low trust in the banking system and limited financial inclusion. However, the adoption of the already implemented CBDC's remains low, which may temper the immediate impact in these economies.

8. Conclusion

The issuance of CBDCs has substantial implications for financial stability and monetary policymaking. Our focus was on monetary policy and how this sovereign digital currency can enhance its efficacy. Based on our findings, CBDCs emerge as an instrument potentially capable of significantly improving transmission mechanisms, giving CBs more direct control over policy execution and allowing for more responsive adjustments to economic conditions. However, as the literature points out, the extent and nature of these impacts depend on the specific design adopted.

In this sense, the implementation of CBDCs can redefine the conduct of monetary policy, both in terms of conventional and unconventional tactics. For example, CBDCs offer CBs greater direct control over liquidity, while expanding the scope of their OMOs, beyond traditional government securities trading. Additionally, CBDCs enable CBs to apply variable, even negative, interest rates on digital holdings, helping overcome the ELB constraint of physical cash. In a financial crisis, the ability to apply negative interest rates would reduce dependence on non-standard tools by strengthening the transmission mechanism. Moreover, CBDCs could support measures like helicopter money, enhancing the efficiency of fiscal-monetary coordination.

The literature analysed in the present work identifies several effects that can strengthen the effectiveness of monetary policy, by leveraging different transmission channels. Firstly, the improvement of the interest rate channel and the strengthening of the bank lending channel stand out. The introduction of CBDCs, whether interest-bearing or not, tends to reinforce the transmission of monetary policy, by creating more competition for deposits and pressuring banks to adjust interest rates faster, facilitating the passage of monetary policy decisions to credit and, consequently, to the real economy. The traditional transmission of short-term rates would also improve its effectiveness, even in very low-interest rate contexts. In the case of interest-bearing CBDCs, additional effects arise in the channels of wealth and substitution, as they directly influence intertemporal consumption decisions.

On the other hand, CBDCs allow CBs to maintain more direct control over systemic liquidity, something that is not possible with private digital currencies such as stablecoins or cryptocurrencies. Such enhanced monitoring would facilitate a more precise adjustment of

monetary policy instruments, including through the management of the monetary base and the setting of interest rates, thereby improving the responsiveness to economic shocks.

As we have seen, a common goal of CBDCs is also to promote financial inclusion, which has significant repercussions on the scope of monetary policy. The digital euro project, for example, underlines the importance of ensuring accessibility for groups traditionally excluded from the financial system. Such an initiative would amplify the reach of monetary policy to populations previously remote from the financial system, as a broader consumer base exposed to interest rates would strengthen aggregate demand responses. In addition, CBDCs could contribute to reducing financial fragmentation. In the case of the digital euro, the explicit objective is to create a pan-European instrument, reducing dependence on non-European payment infrastructures and thus strengthening the strategic autonomy of the EU and its monetary sovereignty.

CBDCs could restore monetary sovereignty in countries with strong foreign currency adoption, increasing the attractiveness of the national currency as a medium of exchange and store of value. On the other hand, the greater flexibility provided by CBDC interest rates could reduce the effects of international contagion resulting from external shocks, thus strengthening the effectiveness of domestic monetary policy.

However, the experience of the ongoing pilot projects demonstrates a preference for issuing CBDCs without remuneration, reinforcing their role as a mere means of digital payment, as is the case with the digital euro. While such a design limits the application of negative interest rates and thus the exceeding of the ELB, non-interest-bearing CBDCs can still improve the effectiveness of monetary policy through indirect means. However, this indirect potential is more limited in times of crisis, when the need to overcome the ELB becomes crucial, reinforcing the importance of non-conventional instruments such as QE and forward guidance.

The present analysis faces some limitations. First, given the absence of adequate empirical data, this analysis relies exclusively on existing literature, which restricts the ability to assess economic impacts more accurately. In the future, as experience with CBDC implementation deepens and more data becomes available, it will be possible to develop research that uses econometric models to assess how the integration of CBDCs can enhance the effectiveness of monetary policy. Additionally, it would be relevant to explore the impacts of CBDCs on the financial fragmentation of the EA.

Appendix: Monetary Policy Approach

Appendix 1. The ECB Monetary Policy Approach

The operational framework of the ECB is structured around a diverse set of instruments that interact dynamically to regulate and influence economic conditions within the EA. As outlined in Table 5, these instruments encompass various types of operations, they include both liquidity management measures, which are calibrated in accordance with prevailing economic conditions to influence interest rates and ensure the effective pursuit of the ECB's primary objective of price stability.

Table 5. Main Instruments applied by ECB

Operations	Liquidity		Maturity	Frequency
	Provision	Absorption		
Open Market Operations				
Main Refinancing Operations (MROs)	✓		One Week	Weekly
Longer-term Refinancing Operations (LTROs)	✓		Three months	Monthly
Fine-tuning Operations (FTOs)	✓	✓	Not standardized	Ad hoc basis
Structural Operations	✓	✓	Not standardized	Regular or non-regular
Reserve Requirements				
Minimum Reserves		✓	Maintenance period	Based on bank's balance sheet items
Standing Facilities				
Marginal Lending Facility	✓		Overnight	At discretion of counterparties
Deposit Facility		✓	Overnight	At discretion of counterparties

Source: Author's own based on Delivorias (2015).

The OMOs¹⁴, represent the ECB's most frequently employed instrument for managing market liquidity and signalling the stance of monetary policy. These operations are categorised according to their nature and objectives, encompassing regular operations such as MROs and LTROs. In addition, the ECB may conduct FTOs, which are extraordinary measures implemented to address specific, often unexpected, circumstances (ECB, 2025a). Moreover, the ECB undertakes structural operations when it seeks to adjust the structural position of the Eurosystem vis-à-vis the financial sector, thereby influencing the amount of liquidity in the system over the longer term (Fernandes & Mota, 2023).

Another important instrument employed by the ECB is the system of minimum reserve requirements, which obliges EA banks to hold funds with the national CBs, calculated based on liabilities such as deposits and short-term debt securities (ECB, 2023). This mechanism plays a crucial role in stabilising money market rates, enabling daily adjustments during the six-to-seven-week maintenance period, and thereby contributing significantly to the mitigation of liquidity fluctuations (Delivorias, 2015). Moreover, reserve requirements increase the structural liquidity shortage in the banking system, enhancing banks' demand for CB funding and reinforcing the ECB's control over monetary conditions through OMOs (Pattipeilohy et al., 2013). The remuneration of these reserves has been set at 0% since September 2023, while excess reserves are remunerated at 0%, unless the deposit facility rate is negative (ECB, 2023).

Complementing the set of conventional instruments, the ECB also employs standing facilities as a mechanism for stabilising liquidity in the interbank market. These facilities operate in the short term to correct deviations from monetary policy objectives (Fernandes & Mota, 2023). They include the marginal lending facility, which allows financial institutions to obtain overnight credit against eligible collateral, and the deposit facility, which enables the deposit of excess liquidity (ECB, 2025b). The interest rates on these facilities form a corridor, with the lending facility rate above the MRO rate and the deposit facility rate below it, directly influencing the cost of credit and conditions in the interbank market. For instance, on 12 March 2025, these rates were set at 2.90% for the lending facility and 2.50% for the deposit facility (ECB, 2025b).

¹⁴ Previously, in the EA, the rediscount rate was also applied, functioning as a lender-of-last-resort mechanism to ensure the solvency of credit institutions within the financial system. In the euro area, this mechanism has been embodied in the form of Emergency Liquidity Assistance (ELA) (Fernandes & Mota, 2023).

During periods of severe economic disruption, such as the global financial crisis of 2008, the subsequent sovereign debt crisis, and the COVID-19 pandemic, traditional monetary policy tools were constrained, particularly as nominal interest rates approached the ELB. In response, CBs adopted unconventional policy measures aimed at influencing broader financial conditions and restoring impaired transmission mechanisms. These measures involved enhanced liquidity provision, asset purchases, and changes to collateral frameworks. As Borio and Disyatat (2009) explain, these balance sheet policies alter private sector portfolio compositions and ease financing constraints, providing monetary stimulus even when policy rates cannot be lowered further. According to González-Páramo (2009), these interventions marked a deliberate and necessary broadening of the monetary policy framework under conditions of heightened uncertainty.

The ECB's initial strategy during the financial crisis focused on balance sheet expansion through LTROs, progressively extending their maturity to twelve months and later to three years. In December 2011 and February 2012, two LTROs totalling approximately €1 trillion provided medium-term liquidity to the banking system, particularly targeting small and medium-sized institutions. At the same time, collateral requirements were eased, and two Covered Bond Purchase Programmes (in 2009 and 2011) were launched to revitalise the bank funding market (Delivorias, 2015).

As the sovereign debt crisis escalated, the ECB introduced the Securities Markets Programme (SMP) in May 2010, purchasing sovereign bonds on secondary markets, with total purchases peaking at around €210 billion. A significant turning point occurred in September 2012 with the announcement of the Outright Monetary Transactions (OMT) programme. Although the OMT was never implemented, its mere announcement, coupled with Mario Draghi's unequivocal pledge to do "whatever it takes to preserve the euro," proved highly effective in reducing market volatility (Delivorias, 2015). The evolution of interventions continued with the introduction of forward guidance in July 2013, followed by the implementation of negative interest rates, with the deposit facility rate falling to -0.10% in June 2014 (ECB, 2022b).

In early 2015, the ECB launched its Asset Purchase Programme (APP) as part of its QE strategy, with the Public Sector Purchase Programme (PSPP) serving as the primary component of this broader framework. Initially planned until September 2016 but subsequently extended, monthly purchases reached approximately €80 billion at their peak,

injecting liquidity into the financial system and reducing borrowing costs for governments and firms. This strategy faced unique challenges, including legal constraints on direct government bond purchases and the need to proportionally distribute purchases among euro area countries. In December 2018, the ECB began scaling down the programme, ending net asset purchases in January 2019 but resuming similar strategies during the COVID-19 crisis through the PEPP (ECB, 2025a).

Amid deteriorating economic conditions brought about by the pandemic, the ECB implemented the PEPP with an initial envelope of €750 billion in March 2020, later expanded to €1.85 trillion, and broadened the APP. Simultaneously, refinancing mechanisms such as the Targeted Longer-Term Refinancing Operations (TLTROs), first introduced in June 2014 to provide long-term funding to banks conditional on their lending to the real economy, were reinforced through TLTRO III, alongside the introduction of Pandemic Emergency Longer-Term Refinancing Operations (PELTROs), offering favourable lending conditions with negative rates to ensure continued credit flow to businesses and households (European Parliament, 2021).

Research on the APP's impact confirms its effectiveness across multiple transmission channels. Using a structural VAR model, Gambetti and Musso (2020) argue that the APP announcement had an immediate impact on economic growth and inflation, leading to increased economic activity and a recovery in prices as measured by the HICP. The yield curve initially flattened before gradually normalising, while equity prices rose, indicating a broadly positive response in financial markets. Moreover, the exchange rate depreciated persistently, supporting European exports, thereby suggesting that the exchange rate channel also played a role. However, the effectiveness of other channels, such as the re-anchoring of inflation expectations, remains less certain.

Those QE policies significantly expanded the ECB's monetary base in 2015, aiming to support economic recovery and reduce long-term interest rates. However, the impact on bank lending was more constrained than initially anticipated (Fernandes & Mota, 2021). While there was some growth in credit extended to firms and households, a substantial portion of the additional liquidity remained "parked" at CBs as excess reserves, reflecting commercial banks' preference for maintaining readily available liquidity to navigate uncertainties, rather than taking on additional risk (Fernandes & Mota, 2021). This behaviour dampened the monetary base multiplier effect, as measured by the M3 aggregate, which

captures the total money supply within the economy. As a result, these policies had to be implemented on a large scale to produce significant impacts on GDP and inflation, given the limited transmission of these measures to the real economy (Fernandes & Mota, 2021). This dynamic is particularly relevant in the EA, where firms are more reliant on bank credit for financing, unlike economies such as the U.S., which will be examined in the Appendix 2, where capital markets play a prominent role in financial intermediation.

Recent studies provide complementary insights into the effectiveness of these policies. Altavilla et al. (2021) estimated that such measures contributed approximately 0.6 percentage points to GDP growth between 2015 and 2020 and supported inflation by around 0.4 percentage points. The coordinated use of these various instruments has proven to be particularly effective in mitigating economic downturns, especially when interest rates approach their ELB. Similarly, Rostagno et al. (2021) observed consistent effects of APP and PEPP announcements on financial market prices, noting that subsequent asset purchase rounds were largely anticipated by market participants. The impact was not evenly distributed across the AE, the peripheral economies, which faced higher financial stress, tended to experience more pronounced declines in yield compared to core economies (Fernandes & Mota, 2021).

Conversely, Pattipeilohy et al. (2013) found that, despite the ECB's substantial balance sheet expansion, the effects of various measures were moderate and primarily temporary. While LTROs contributed to the short-term decline in sovereign bond yields and the SMP had momentary impacts on debt markets, questions remain regarding the long-term sustainability of these effects and the potential side effects of prolonged use, such as excessive risk-taking by financial intermediaries and declining bank profitability.

Appendix 2. The FED Monetary Policy Approach

Prior to the global financial crisis, the FED System pursued a stabilising monetary policy framework that responded to both inflationary pressures and the output gap (Rodriguez-Rodriguez et al., 2024). This approach was implemented through the Federal funds rate¹⁵ and OMOs¹⁶, including the use of instruments such as Reverse Repurchase Agreements and Temporary Repurchase Agreements. Nevertheless, the FED's operational approach differs in important respects. These distinctions are evident in Table 6, which summarises the key features of the principal instruments employed by the FED.

Table 6. Main Instruments applied by the FED

Operations	Liquidity		Maturity	Objectives
	Provision	Absorption		
Open Market Operations				
Overnight Reserve Repurchase Facility (ON RRP)		✓	Overnight	Anchor short-term interest rates
Reverse Repurchase Agreement (Reverse Repo)		✓	Short-term	Manage short-term interest rate stability.
Temporary Repurchase Agreements (Repos)	✓		Contractually specified future redemption date	Manage short-term market liquidity
Permanent Purchases/ Sales of Securities	✓		Not standardized	Influence long-term monetary conditions
Management Tools				
Discount Window Lending	✓		Temporary/ Short-term	Provide emergency financial system liquidity
Interest on Reserve Balances (IORB)		✓	Continuous	Transmit monetary policy signals
Reserve Requirements		✓	Maintenance period	Ensure banking system stability

Source: Author's own based on FED (2021).

¹⁵ The federal funds rate serves as the key policy rate that influences the interbank lending rate, namely, the overnight rate at which depository institutions lend reserves to one another.

¹⁶ Through this mechanism, CBs permanently or temporarily purchase or sell assets issued or backed by the US Treasury, in the case of the FED, or by government entities. Depending on the objective, such operations either increase (through asset purchases) or decrease (through asset sales) the reserves within the banking system.

During the most recent financial crises, notably the 2007–2009 crisis and the one triggered by the COVID-19 pandemic, the FED restructured its operational framework, modifying the use of traditional instruments and employing unconventional mechanisms to ensure market stability and the effectiveness of monetary policy, as we have also examined in the ECB's case. OMOs played a crucial role, being adjusted in response to liquidity needs and the constraints imposed by the environment of extremely low interest rates (FED, 2021).

Before the global financial crisis, the monetary framework of the FED was based on scarce reserves, providing a limited quantity of reserves sufficient to satisfy the demand of financial institutions at the FOMC's target federal funds rate. In this approach, short-term interest rates were primarily managed through frequent OMOs, in which these daily adjustments influenced financial conditions, notably the consumption and investment decisions of economic agents (FED, 2021).

As the crisis intensified in 2008, the FED rapidly reduced the federal funds rate, lowering it from 5.25% in September 2007 to a target range of 0 to 0.25% by December 2008, reaching historically low levels aimed at stimulating borrowing and investment, as was the case with the ECB (Logan, 2020; Zheng, 2024). With the lower bound reached, conventional monetary tools became insufficient, leading to the adoption of extraordinary measures such as forward guidance and QE programmes, including Large-Scale Asset Purchases (LSAPs). These asset purchases expanded the FED's balance sheet from approximately \$870 billion in mid-2007 to around \$4.5 trillion by 2014, with the aim of reducing long-term interest rates and supporting broader economic recovery (FED, 2021; Zheng, 2024). The disruptions in financial markets from 2007 exposed critical limitations in the scarce reserves system, prompting the FED to shift towards an abundant reserves regime, where the primary tool for managing short-term interest rates became the IORB, formally implemented in 2021 (FED, 2021; Logan, 2020). By adjusting this rate, the FED can influence the opportunity cost of holding reserves.

Additionally, the FED introduced the ON RRP facility as a key instrument for absorbing excess liquidity, offering a secure, short-term investment option to a broad range of financial market participants, thereby reinforcing the lower bound for short-term interest rates (FED, 2021). During both the 2007-2009 financial crisis and the COVID-19 pandemic, the FED also made extensive use of its discount window and established dollar liquidity swap lines with foreign CBs to support global financial stability and maintain the flow of

credit to households and businesses (FED, 2021). The final measure included conducting stress tests on major banks, led by the U.S. Treasury and the FED, with subsequent capital injections where needed to restore confidence in the financial system (Zheng, 2024).

Empirical literature supports the relative effectiveness of these interventions. For instance, Hamilton and Wu (2012) demonstrate that altering the composition of public debt through long-term asset purchases can flatten the yield curve, although its impact remains limited outside the context of the ZLB. Additionally, Gilchrist et al. (2015) present two distinct scenarios for monetary policy: In a conventional environment, the effects on long-term interest rates are modest. However, under ZLB conditions, measures such as QE significantly enhance the FED's ability to influence financing costs in the market.

Eberly et al. (2019) suggest that the broader macroeconomic impact of these operational changes. The slope policies¹⁷ substantially contributed to the post-2008 labour market recovery, reducing the time required to reach the non-accelerating inflation rate of unemployment (NAIRU) and mitigating deflationary pressures. Despite these advancements, the authors note that GDP recovery remained constrained by structural factors and the limitations imposed by the ZLB. The authors even estimate that a federal funds rate near -5% would have been required to more effectively stimulate the economy, though this is an impractical level within the conventional bounds of monetary policy.

Currently, the FED continues to operate within an abundant reserves regime, with ON RRP and IORB serving as key tools for regulating short-term interest rates. The elimination of reserve requirements in March 2020 further solidified this approach, shifting the focus from active reserve management to rate-setting mechanisms, consistent with a system characterised by ample liquidity.

¹⁷ Slope policy encompasses a set of additional tools within the current monetary framework, designed to influence the shape of the safe-asset yield curve. This approach includes measures such as forward guidance, Summary of Economic Projections, LSAPs, and adjustments to the maturity profile of CB holdings. These instruments collectively impact the term structure by either shaping market expectations about future short-term interest rates or directly influencing longer-term yields (Eberly et al., 2019).

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