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CBDC in the Euro Area and Implications for Commercial Banks

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Introduction

Due to the growing trend of digitalisation, an increasing portion of payments is now conducted online[1]. Consumers opting for online shopping leads to the use of banknotes and coins for payments to decrease and consequently the role of central banks to shrink. Today there is no option to use central bank money for electronic transactions, the public (businesses and individuals) rely exclusively on private money issued by commercial banks. This scenario is fuelling the debate about whether central banks should issue a retail central bank digital currency (CBDC) and which characteristics it should have. The European Central Bank (ECB) is now examining the potential issuance of the digital euro. The digital euro would be the electronic counterpart of cash for online transactions. It would be accepted at a universal level in the euro area for payments in physical shops, online and from person to person. The digital euro would combine the safety of central bank money with the convenience of modern digital payments. Rather than replacing private-sector money, it would complement existing cash and bank deposits, ensuring that the public can continue to use central bank-issued money even as payments become predominantly digital. The ECB plans to implement the digital euro in a two-tier model, where private intermediaries (such as banks and other payment service providers) would distribute and manage digital euro accounts, while the central bank maintains the underlying liability. The objectives behind a digital euro are multiples. A primary goal of all central bank digital currencies is to preserve the role of central bank money. By offering a risk-free digital payment option, authorities aim to ensure that central bank money remains widely used and accessible. A digital euro would also give the public free digital access to legal tender, promoting financial inclusion and choice in everyday payments. Additional objectives include boosting payment efficiency, fostering innovation and strengthening European monetary sovereignty by reducing dependence on foreign-dominated card networks.

[1] European Central Bank. (2024).

The introduction of a retail CBDC also raises important risks, particularly regarding financial stability and the traditional role of banks[2]. By allowing the public to hold central bank money in digital form, a widely adopted digital euro could draw substantial deposits away from commercial banks[3]. In normal times this shift might be gradual, but in a crisis scenario the availability of a risk-free digital alternative could potentially accelerate bank runs, as depositors rapidly convert bank deposits into digital euros at the first sign of distress[4]. Large-scale outflows of deposits could disintermediate banks, shrinking their deposit funding and constraining their capacity to lend, with negative repercussions for credit creation and bank profitability. These concerns have made the design of the digital euro a critical aspect of the project, particularly its usage limits and remuneration policy. To mitigate the risk of deposits outflows, policymakers have proposed measures such as holding limits (capping the amount of digital euro individuals can hold) and reverse waterfall mechanisms that discourage the conversion of large volumes of bank deposits into CBDC[5].

A widely adopted CBDC would affect balance sheets of both central banks and commercial banks[6]. In response to the changing composition of their assets and liabilities, commercial banks will have the possibility to consider multiple adjustment strategies. Banks will evaluate profitability, liquidity requirements and funding needs. They will decide whether to modify the liabilities or assets side of their balance sheets, ultimately determining whether to reduce their overall size or keep it unchanged.

The thesis is organised as follow: chapter I examines the project of the digital euro and its main features; chapter II explores CBDC implication for financial stability; chapter III focuses on the impact of CBDC introduction on commercial banks.

[2] Ahnert et al. (2023).
[3] Burlon et al. (2024).
[4] Ahnert et al. (2023).
[5] European Central Bank. (2023).
[6] Auer et al. (2024)

Chapter I. The Digital Euro Project

This chapter explores the foundations and rationale behind the European Central Bank's digital euro project. Section 1.1 examines the transformation of payment practices in the euro area, highlighting the increasing preference for digital transactions and the decline in cash usage. This shift shows the need for a public digital payment alternative. Section 1.2 discusses the digital euro as a necessary instrument to preserve the ECB's monetary policy influence and ensure the continued presence of central bank money in an increasingly digitized financial ecosystem. Section 1.3 outlines the key benefits of the digital euro, including increased financial inclusion, payment efficiency, monetary sovereignty, and privacy protection. Section 1.4 provides a detailed look at the proposed implementation model and the functionalities of the digital euro, focusing on accessibility, infrastructure, and legal framework. Section 1.5 presents the roles and responsibilities of Payment Service Providers (PSPs), who would act as intermediaries between the ECB and users. Finally, Section 1.6 addresses the importance of holding limits and the waterfall/reverse waterfall functionalities as key design elements to mitigate risks to financial stability and deposit disintermediation. Together, these sections provide a comprehensive overview of the motivations and design of the digital euro within the broader monetary system.

1.1 Evolving payment practices

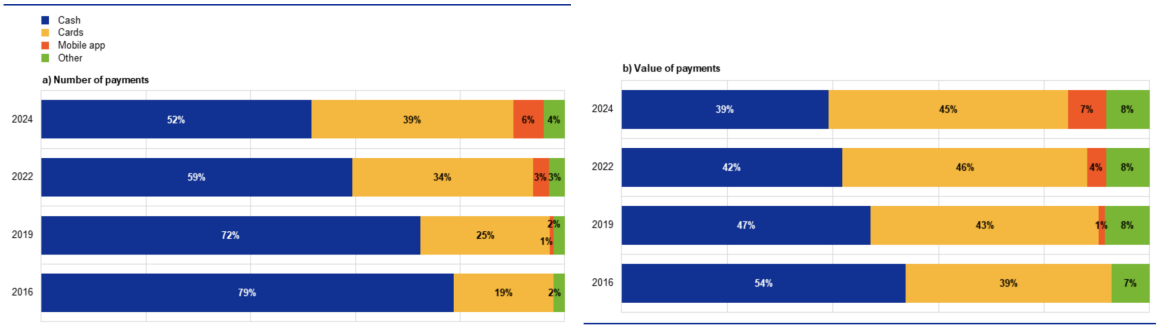
In our contemporary monetary system, it is possible to execute financial transactions via public or private means of payments. Public money is represented by cash, or actual money, and it is issued by central banks. Because the monetary authority is directly liable for it, money is considered a public good. Private money, on the contrary, is created by commercial banks, usually in the form of bank deposits. The landscape of payment systems in Europe has rapidly advanced during the last years, with the transformation of a wide range of methods, including but not limited to cash, card transactions, digital wallets and bank

transfer[7]. Companies have significantly boosted their investments on information and communication technologies to enhance productivity gains they offer. The continuous process of digitization has caused major modifications in the overall structure of the economy. Cash usage had already been declining in some advanced economies even prior to the COVID-19 pandemic due to two main trends. Consumers prefer to make purchases online and pay in physical stores through digital channels, using cards, mobile devices and digital wallets.

To gain a deeper understanding of the evolving payment practices, the ECB has carried out surveys since 2016 to investigate the payment attitudes and behaviours of consumers within the euro area[8]. The share of cash payments is continuing to decline as citizens are increasingly executing payments via online channels. This phenomenon is being supported by a transition from purchases in physical stores to online purchases. At the same time, cash continues to be the most frequently used payment instrument at point of sales and for person-to-person payments, although Euro area consumers have been using non-cash instruments more frequently and cash less often to pay at the point of sale (POS). In 2024, as stated by the report SPACE 2024[9] of the ECB, cash was used in 52% (59%[10]) of transactions, but the share of cash has declined, reflecting the decreasing preference for cash over non-cash payments. Payments made at the POS declined in favor of online paymentents, 75% (80%) of day-to-day payments were made at the POS and 4% (4%) were person-to-person (P2P) payments, while 21% (17%) of consumers' day-to-day payments were made online. In terms of payment value, 58% (68%) of day-to-day payments were made at the POS, 6% (5%) as P2P payments and 36% (28%) online. In terms of value, the most important single payment instrument was cards, with a share of 45% (46%). Cash had a share of 39% (42%). The most frequently used instrument for online payments was cards, representing 48% (51%) of transactions. The share of e-payment solutions, i.e. payment wallets and mobile apps, was 29% (26%).

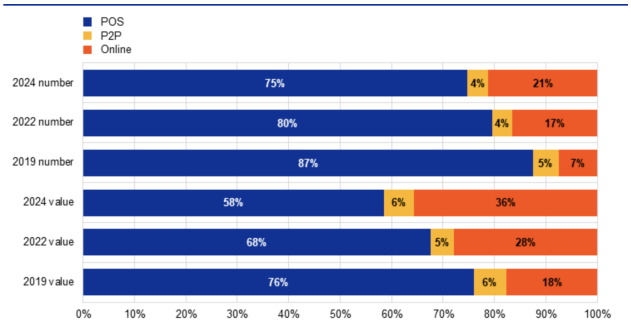
[7] European Central Bank. (2024).
[8] Esselink et al. (2017).
[9] European Central Bank. (2024).
[10] Percentages in brackets represent 2022 figures.

Figure [1]: [Share of payment instruments used at the POS, euro area, 2016-24]



Sources: ECB, calculations based on De Nederlandsche Bank and the Dutch Payments Association (2020, 2022, 2024) and the Deutsche Bundesbank (2018, 2022, 2024). Notes: The "Cards" category includes physical cards (debit and credit cards) and prepaid cards. The "Other" category includes bank cheques, credit transfers, direct debit, loyalty points, vouchers and gift cards and other payment instruments. Mobile payment apps can be based on payment cards.

Figure [2]: [Number and value of day-to-day payments by payment situation, euro area, 2019-24]



Sources: ECB, calculations based on De Nederlandsche Bank and the Dutch Payments Association (2020, 2022, 2024) and the Deutsche Bundesbank (2018, 2022, 2024). Note: Percentages may not add up to 100% due to rounding.

As shown in figure 1 the share of cash decreased gradually from 2016 to 2024 in favor of cards (for the exception of 2024 value of payments which decreased by 1% with respect to 2022), mobile apps and other instruments. Figure 2 shows the fall in the share of the number

and value of day-to-day payments proceeded at POS in the period 2019-2024, while the share of payments conducted online increased overtime.

A decline in the use of cash reduces the central role of the ECB, since the ECB influences monetary policy and stabilizes the money supply and interest rates also through the issuance of central bank money. If cash usage declines sharply and is not replaced by another form of central bank money (digital euro), the public interacts only with private money, reducing the monetary system's direct link to the central bank.

These changes have incentivized central bankers to consider the implementation of a retail digital form of currency. A retail CBDC would provide numerous advantages, offering the chance to enhance payments by using a technologically advanced version of central bank money that maintains the essential qualities of finality, liquidity and integrity that only the central bank can offer[11].

The European Central Bank in 2019 initiated preliminary research on the feasibility of a digital euro, exploring its potential implications for the financial system. In October 2020, the ECB published the *Report on a Digital Euro*[12], which examines the potential issuance of the digital euro, a central bank digital currency, by the Eurosystem. Subsequently, in July 2021, the ECB formally launched the digital euro project. The *Investigation Phase*, a two-year period dedicated to evaluating the digital euro's design features, distribution models, and broader policy implications, ran from October 2021 to October 2023. Following this phase, in November 2023 the ECB transitioned into the *Preparation Phase*, during which it is finalising the scheme rulebook, selecting providers and diving deeper into technical aspects. As the digital euro is a common European project, the Eurosystem's technical work during the preparation phase is being carried out in parallel with the legislative process being conducted by co-legislators. By October 2025, the Governing Council will decide whether to move to the next phase and proceed with the rollout of the digital euro.

[11] Auer et al. (2021).
[12] European Central Bank. (2024).

1.2 Digital Euro Necessary to Preserve the Role of the ECB

The nature of central banks' CBDC issuance plans is a "conservative" reaction to profound technological and preferential shifts in the use of money as a means of payments[13]. The digital euro aims at preserving the current role of the European Central Banks while guaranteeing economic efficiency and stability through the use of public money in a digitalized society. Essentially, Central banks according to their announcements do not aim to change the monetary system by issuing CBDC nor to expand their existing role.

Central banks come into close contact with governments, developing relationships that evolve over time. Central banks have a central role in the economy because of these relationships, their legal status, their responsibilities and the functions that they are supposed to perform. These functions are typically difficult or impossible for the private sector to accomplish, they include ensuring monetary stability and managing crises that arise from market failures. Central banks' special legal status enables them to intervene effectively where private financial institutions cannot. The ECB functions and tasks concern the definition and the implementation of the monetary policy of the euro area, the conduction of foreign exchange operations, the holding and management of foreign reserves, the promotion of the smooth operation of payment systems, the contribution to the safety and soundness of the banking system and the stability of the financial system by carrying out effective banking supervision. Central banks act as the ultimate source of credit for commercial banks in times of financial distress, thereby facilitating the continuous operation of the banking system. Central banks are responsible for the issuance of base money, banknotes and bank reserves; the two circuits run in parallel.

The continued use of central bank money by society is considered important for several reasons. Firstly, central bank money represents a risk-free means of payment because it is backed directly by the central banks, thus there is no chance of default; in contrast money stored in a commercial bank account depends on the bank not going bankrupt. Secondly, the continued use of central bank money would guarantee a two-layer monetary system, including central bank money and commercial bank money. Commercial bank money is a

[13] Bindseil et al. (2023).

promise to be converted into central bank money on demand, this convertibility ensures trust in the system. Private banks are profit-driven, so they might not prioritize social values, like inclusiveness and privacy; while central banks design money as a public good protecting these values. Moreover, if central bank money had to disappear and only a few private payment companies would continue to exist, they would be able to abuse market power, increase fees, control terms and conditions of payments and exploit user data[14]. CBDC would maintain competition and offer an alternative. CBDC would support geopolitical resilience and strategic autonomy as many leading private payment platforms are owned by foreign companies[15]. If a country relies only on them for payments, it loses control over its own financial infrastructure. Central bank money ensures a sovereign, national payment option, helping a country maintain autonomy in case of political or economic conflict. In fact, by issuing CBDCs, central banks can ensure that public money remains the ultimate form of payments, even in a digital age. Central banks have a central influence on monetary policy and on stabilizing money supply and interest rates, especially during the crises. In the event of a decline of length of central bank balance sheets this function will no longer be fulfilled. Additionally, the use of CBDCs could also improve transparency as all transactions are recorded and easily traceable.

Furthermore, a CBDC could potentially enhance the confidentiality of digital transactions. Private companies, currently, have the possibility to profit from the data contained in electronic transactions, which could pose a significant threat to privacy. The rise of big tech firms that offer financial services and the rapid development of artificial intelligence, increases this risk. While data protection regulations seek to prevent misuse, they may not always be able to evolve as rapidly as technological advancement, as evident by past instances of data breaches and exploitation by tech companies. It may be possible to increase, rather than decrease, the confidentiality of electronic payments through the introduction of a digital currency by an independent public institution like the central bank, which has no interest in exploiting personal payment data for any purpose.

[14]Panetta. (2021).
[15]Panetta. (2022).

Central banks now have a unique opportunity to reestablish control and influence over the payment system through CBDCs, which simultaneously guarantee the confidence of the public in central bank currency.

1.3 Benefits of the Digital Euro

The digital euro would be under European governance and it would provide a unique solution for the entire euro area to the online payment issue. Current digital payments are executed in a fragmented framework across national markets, countries adopt different technologies[16]. Frequently consumers are obliged to rely on non-European payment providers as a result of the absence of European competitors. A successful digital euro could limit Europe's dependence on private foreign agents, counterweighting their market dominance and fostering competition. The implementation of new technologies and platforms to facilitate digital payments would reshape the European landscape, making it more innovative and self-sustaining. The introduction of the digital euro would strengthen the strategic autonomy of the European payment ecosystem as a whole and reinforce monetary sovereignty[17].

Consumers will be able to pay with the digital euro across Europe at any time free of any charge. It will give people the option to pay both online and offline, still using a public means of payment[18]. Today digital payments can be conducted exclusively using a private means of payment provided by commercial banks. Digital payments can be executed both online and in physical stores via credit or debit cards, NFC (contactless) payments and QR codes.

The digital euro would be safe and easy to manage. It would provide a high level of privacy to the user, as the Eurosystem could not identify people based on their payments transactions[19]. Furthermore, only the payer and the payee would have access to the transaction details of offline digital payments. The use of the digital euro would be easy for all the consumers, fostering financial inclusion. The digital euro aims to be inclusive,

[16] European Central Bank (2020).
[17] European Central bank. (2020).
[18] European Central bank. (2023).
[19] European Central bank. (2023).

ensuring accessibility for people with disabilities and those with no access to a bank account or lacking digital or financial skills. Merchants would mandatorily have to accept the digital euro and intermediaries would be supervised in the distribution to their clients to achieve a digital currency universally usable and accessible. A draft legislative proposal establishing the legal framework for the possible digital euro has been presented by the European Commission in June 2023[20]. The European Commission is putting forward two proposals within a 'single currency package' to ensure the use of banknotes and coins and set out a framework for the possible new digital form of the euro. The digital euro would complement cash, not replace it. Both physical currency and other private electronic means of payment would coexist with the digital euro. The digital euro reflects the growing public interest in completing payments online and represents a strategy for central banks to maintain their relevance in the evolving financial landscape.

Intermediaries and merchants could benefit from the digital euro. Intermediaries, such as supervised banks, would play a central role in distributing the digital euro. They would be the middle point between the European Central Bank and individuals, merchants and business. Banks would perform all end-user services related to the digital euro issue. The digital euro could represent a new business opportunity for commercial banks. In light of the pan-European quality of the digital euro, intermediaries would have a competitive advantage on existing competitors. The present online payment landscape is fragmented and most private innovations tend to concentrate on a national level, satisfying specific domestic market needs. The digital euro would present commercial banks the opportunity to broaden their customer base, encouraging innovation and enhancing competition in the euro area's digital payment sector. Furthermore, intermediaries responsible for distributing the digital euro would receive economic incentives similar to those associated with other digital means of payments. Merchants could also benefit from the digital euro as well. The digital euro would allow merchants to receive online payments immediately without any additional costs. Given its acceptance across the entire euro area, the digital euro would represent a more efficient alternative to the prevailing fragmentation in payment methods. The digital euro

[20]European Commission. (2023).

would strengthen merchants' bargaining power with payment solution providers because it would introduce a public, low-cost alternative to existing private payment systems, giving merchants more leverage to negotiate lower fees and better conditions.

The digital euro would be the evolution of cash, maintaining its nature of public good. The digital euro compensation model aims at preserving this role of public good, while incentivizing adequately PSPs to distribute the digital euro. Four core principles have to be considered for the establishment of the digital euro compensation model: (1) free basic use by private individuals, (2) network effects generating economic incentives for acquiring PSPs and merchants, (3) comparable economic incentives for distributing PSPs, (4) the Eurosystem bears its own costs, as with production and issuance of banknotes

Currently, payment services generate about 3% of Italian banks' total revenues[21]. If the distribution model involves banks acting as intermediaries then banks might earn new revenues by offering CBDC-related services.

1.4 Implementation and Functionality of the Digital Euro

The ECB is currently exploring how the digital euro could be implemented. Firstly consumers will have to establish a digital wallet, it would be possible to set it up through a post office or a bank. Money can be added into the wallet by depositing cash or via a linked bank account. After the transfer, individuals can initiate transactions using the digital euro stored in their wallet.

Whenever receiving payments in digital euros, these funds may be retained within the wallet, limited to certain constraints, or transferred to a bank account. This process could either be managed manually or automatically. Digital euro payments would always be safe and instant – whether in physical stores, online shops or between people.

The digital euro would be accessible not only to people, companies and public entities that reside or are established in a euro area Member State on a temporary or permanent basis[22]. People who travel for personal or professional purposes, or who were previously residents or

[21] Auer et al. (2024)

[22] European Central bank. (2023).

established in a nation that is part of the euro area, may also have access to the digital euro. Additionally, for individuals, business and public entities non residing or established in a euro country will be possible to benefit from the usage of the digital euro. It will be possible to obtain a digital euro account with payment service providers established or operating in a country which is a Member of the European Economic Area or in a third country, provided that there are prior arrangements between the EU and third countries or arrangements between the ECB and national central banks in non-euro area Member States.

The digital euro will be available via a mobile app or a physical card. In order to ensure that the digital euro could be used by all members of the society, post offices will be present in every region of the euro area. The capillary distribution will ensure the inclusiveness of people with functional limitations or limited digital skills, elderly people and those with disabilities. It will guarantee free support and access to digital euro services to individuals at risk of digital financial exclusion, especially to people without a bank account. This includes face-to-face assistance when opening a digital euro account and using basic services.

A single set of rules and procedures will be applied to standardise digital euro payments, ensuring accessibility across all European countries. The digital euro rulebook will encompass these rules and it will address multiple aspects[23]. It will define the rules for the functional and operational model of the digital euro, its management, technical requirements and risk management provisions. To draft the digital euro rulebook, the Eurosystem has created a Rulebook Development Group in the project's investigation phase and is continuing its work in the preparation phase. The group consists of professionals with experience in finance and payments from both the private and public sector. Senior members are selected by different European stakeholder associations involved in the European retail payments market; the Rulebook Development Group includes representatives of the national central banks. This organization guarantees diversity in the development of the standardised rules as each member represents a particular association. This group will collect inputs from various stakeholders to ensure that the rules governing the digital euro are comprehensive and address the needs of all relevant parties involved. The stakeholders involved are private companies,

[23]European Central bank. (2023).

civil society organisations and potential users and the feedback is collected through surveys, interviews and focus groups. Private companies provide recommendations and proposals on the technical aspects of the digital euro. The Eurosystem is experimenting with various technologies, both centralised and decentralised, for the development of the digital euro, including distributed ledger technologies. However, no final decision has been made regarding the technology chosen for the implementation of the digital euro.

The digital euro would never be programmable money, meaning that its usage would not be predefined, it would not have limitations regarding location, time or with whom people can transact. If the consumers are interested in automatic payments, it would be possible to facilitate transactions executed periodically by setting up an automatic payment to instantaneously transfer the digital euro to another account. Intermediaries, such banks, could offer additional services to their customers, making the digital euro more appealing.

1.5 Services Provided by PSPs

The collaboration between the public and private sectors would make the digital euro available, maximizing their respective advantages. People would open and manage digital euro accounts with Payment Service Providers (PSPs), similarly to existing digital payments or to accounts from which cash can be withdrawn[24]. However, the digital euro consumers hold would be a liability of the central bank, analogous to cash. PSPs would act as intermediaries between the central bank and end users. PSPs would handle customer interactions, ensuring that users can easily access, use, and manage their digital euro holdings. They would perform the initiation and validation of payments. In the performance of these tasks, PSPs would therefore be responsible also for conducting the necessary AML/CFT checks[25] (in which the Eurosystem would not be involved).

The Eurosystem would provide PSPs with the necessary support services, as part of the back-end infrastructure. The digital euro services would be provided by all PSPs meeting the

[24]European Central Bank. (2023)

[25] Anti-Money Laundering (AML), Counter-Terrorism Financing Rules (CTF)

requirements established by the Payment Services Directives[26] for the provision of payment account services and that provide retail payment services. Services encompass three main areas: user management, liquidity management and transaction management.

The management framework is designed to ensure inclusivity, security, and portability, while maintaining alignment with European regulations and user privacy standards. User management encompasses onboarding and offboarding, payment instrument management, linking digital euro holdings to a commercial bank account, and lifecycle management processes enabling end users to interact with their digital euro account at a PSP. The onboarding process is the gateway for users to access digital euro functionalities. Users can be onboarded either remotely or in person. Upon successful onboarding, individuals and business users receive a Digital Euro Account Number (DEAN), which acts as a unique identifier for transactions and access via the digital euro app or through a functionality integrated in existing PSP's proprietary application. It will be possible to register aliases, such as a mobile phone number, to facilitate user-friendly payment initiation. Upon request, for users who may prefer or require an alternative to mobile or digital access a physical card will be available. To prevent account duplication, PSPs are required to consult a central onboarding repository. If a user has previously been onboarded through a different PSP, they must request portability of their account and holdings to the new provider. Each user is permitted only one digital euro account, ensuring a centralized and non-fragmented system. To terminate their digital euro relationship with a given PSP at any time users will follow the offboarding process. PSPs must defund accounts before deactivating them, terminate recurring payments, unlink commercial accounts, and disable all payment interfaces. For business users, the process may be deferred to accommodate pending refund obligations. Users can link multiple commercial bank accounts to a single digital euro account, but designate one for automated founding, defunding, waterfall and reverse waterfall. Lifecycle Management concerns the possibility to update profile settings, set limits, manage linked accounts, check transaction history, and enable/disable features. Users can authorize

[26] Directive (EU) 2015/2366 of the European Parliament and of the Council of 25 November 2015 on payment services in the internal market, amending Directives 2002/65/EC, 2009/110/EC and 2013/36/EU and Regulation (EU) No 1093/2010, and repealing Directive 2007/64/EC (Text with EEA relevance)

third-party providers to access accounts for services like account aggregation or payment initiation.

Liquidity management enables smooth and uninterrupted execution of transactions. It is the mechanism that guarantees funding and defunding. Payment Service Providers (PSPs) are responsible for ensuring continuous access to digital euro funding and defunding services, operating on a 24/7/365 basis. End users may fund their digital euro accounts either through linked commercial bank accounts or cash, with the latter requiring physical infrastructure such as ATMs or cash-in-shop services. In the case of offline digital euro holdings, only manual funding and defunding are permitted, and operations must occur while the device is online. Offline holdings are stored on the user's device and are constrained by holding limits. To facilitate user experience the system incorporates two automated liquidity management tools, minimizing transaction failures and reducing the need for manual intervention by users. Waterfall functionality automatically transfers excess digital euro balances to a linked commercial bank account once a predefined threshold is reached, while reverse waterfall functionality allows a user to initiate a payment even when their digital euro balance is insufficient by automatically drawing money from a linked commercial account.

Transaction management includes payment initiation, user authentication, confirmation, refunds, dispute resolution and recurring payments. End users initiate payments through the digital euro app, a proprietary app or online interface of the PSP, or a payment card. PSPs are responsible for validating the transaction, conducting anti-money laundering (AML) and fraud checks, and authenticating users. Once validated, transactions are executed without exposing personal identifiable information to the Eurosystem. Pre-authorisations are supported for payment of uncertain amounts or timing (e.g., car rentals or hotel bookings). In these cases, the system can reserve a maximum amount for a fixed timeframe, with final settlement occurring upon confirmation. The system allows for recurring P2P and e-commerce payments. Users can configure parameters such as frequency and amount through their PSP. A digital euro payment could only be refunded via digital euro, in line with market practice, to prevent, for example, money laundering.

Disputes may arise from technical errors, fraud, or disagreements over consent or transaction amounts. The ECB foresees a three-tiered dispute resolution process: (1) Pre-dispute

resolution– End users and merchants attempt resolution via their PSPs. (2) Formal dispute resolution– PSPs actively engage to resolve the dispute. (3) Arbitration– In unresolved cases, a neutral third party (not the Eurosystem) such as an ombudsman or arbitration body intervenes.

1.6 Holding limits and reverse waterfall functionality

How could it be possible to determine the optimal quantity of digital euro to be issued, and what limits should be imposed on the maximum amount of CBDC that the economic system could sustain? In recent years literature has been growing rapidly, focusing on the macroeconomic consequences of issuing CBDCs. Much of this literature focuses on the trade-off between the potential benefits of CBDC as a safe and innovative means of payment and the risk of bank disintermediation through deposit substitution.

To preserve financial and monetary stability, holding limits were identified as an effective measure to prevent excessive outflows from commercial bank deposits into digital euros. Merchants, governments and public authorities would initially have a zero holding limit, meaning they would not be able to accumulate holdings of digital euros, any payments received would be transferred immediately to their commercial bank account[27].

Bindseil and Panetta, respectively the Director General of Market Infrastructure and Payments at the European Central Bank (ECB) and Governor of the Bank of Italy, in 2020 suggested a digital euro holding limit of €3,000 per person aiming at containing the impact on banks' liquidity risks and funding structures[28]. The digital euro is intended as a means of payment, not an investment vehicle. The holding limit discourages individuals from using digital euros as a store of value, which could otherwise lead to disintermediation of the banking sector.

The upper bound would prevent the materialisation of high deposit outflows. This would correspond to a total issuance of approximately €1 trillion, based on an estimated eligible

[27] European Central Bank. (2023)
[28] Bindseil & Panetta (2020).

euro area population of 340 million[29]. Notably, this figure aligns with existing monetary aggregates: the current volume of banknotes in circulation in the euro area slightly exceeds €3,000 per capita (totaling roughly €1.2 trillion), while the Eurosystem's securities holdings—including investment and policy portfolios—surpass €3 trillion. Additionally, commercial banks in the euro area hold excess reserves in excess of €2 trillion. Setting a per capita amount of €3,000 for tier one CBDC is aligned with the average monthly net income of euro area households, the normal payment function of money would be covered.

The ECB announced a so- called "waterfall functionality"[30]. Although holding a commercial bank account—or establishing a link between such an account and a digital euro wallet—would not be a requirement for individuals to access digital euro services, it is anticipated that many users would opt to connect the two for greater ease in managing funds. This connection would enhance the overall convenience of transactions in several ways. Firstly, individuals would be able to receive payments even if doing so would cause their digital euro balance to exceed the prescribed holding limit. In such cases, any surplus funds would be automatically redirected to the linked commercial bank account. This automatic reallocation process is referred to as a *"waterfall functionality"*. Users could also predefine a personal threshold below the official holding cap to trigger this transfer. Secondly, users would not need to preload their digital euro wallet in advance to make payments. If the wallet lacks sufficient funds, the necessary amount could be instantly transferred from the connected bank account. This mechanism is known as *"reverse waterfall functionality."* Users would have the flexibility to activate either the waterfall or reverse waterfall feature—or both—based on their preferences. These mechanisms integrate funding, defunding, and transaction processing into a seamless operation, with minimal or no delay from the user's perspective. The waterfall functionality would be essential to maintain financial stability. The waterfall function, transferring automatically excess CBDC holdings to private bank accounts, helps avoid a sudden shift of funds from banks to central banks.

[29] Meller et al. (2023).
[30] European Central Bank. (2023).

Chapter II. Financial Stability Implications of CBDC

The introduction of a CBDC may lead customers to move their funds from traditional bank accounts to CBDC accounts, causing an outflow of deposits from commercial banks; this mechanism is discussed in section 2.1. Banks typically rely heavily on retail deposits as a stable funding source. An outflow of these deposits due to CBDC adoption would force banks to adjust their balance sheets because the outflow could have implications for their profitability, capitalization, and liquidity, while setting in motion a series of indirect effects on the economic system more broadly. The scale of the deposit outflow depends significantly on how the CBDC is designed (interest-bearing vs. interest-free, holding limits, privacy level). During the initial period of the introduction of a CBDC, there will be considerable uncertainty about its demand and it will be particularly relevant investigating how design choices could limit the substitution of retail deposits.

CBDC affects financial stability through three main mechanisms: CBDC influences run dynamics on financial institutions (section 2.2), it alters the credit provision by banks in times of crisis (section 2.3) and addresses financial stability risks from stable coins (section 2.4)[31]. Each section contributes to a comprehensive understanding of the trade-offs and safeguards involved in maintaining financial stability in the context of CBDC integration.

2.1 Potential Outflow of Deposits from Commercial Banks

In the paper "The Optimal Quantity of CBDC in a Bank-Based Economy."[32] the authors present a framework where liquidity services are provided by three assets: bank deposits, cash and Central Bank Digital Currency (CBDC). Due to the imperfect substitutability between those, the issuance of CBDC only partially replaces the fall in cash and deposits, leading to an expansion of liquidity services. Consequently, the central bank balance sheet expands, resulting from the increase in CBDC, which is larger than the joint reduction of cash and reserves. Central bank liabilities increase because commercial banks, in order to comply with the reserve requirement, in response to the fall in deposits, draw down reserves

[31] Carapella et al. (2024)
[32] Burlon et al. (2024)

held at the central bank but less than proportionally. The aim of commercial banks is to maintain an equilibrium between liabilities and assets: a decrease in liabilities (deposits), must be balanced by a decrease in assets (reserves held at the central bank).

Central bank's liabilities would partially shift from costly reserves to zero or negative interest bearing CBDC, increasing profitability and enlarging the balance sheet. Profits increase for the central bank because liabilities are less expensive. Seigniorage is the profit a central bank earns from money creation and it is basically the difference between income from assets and interest paid on liabilities. This additional revenue relaxes the government's budget constraint, reducing the need for further taxation or public borrowing. Consequently, the government may lower taxes or increase lump-sum transfers to households in order to reallocate fiscal resources. Both channels stimulate aggregate private consumption, resulting from higher disposable income.

Funding costs for commercial banks rise due to the shift from deposit fundings to more costly borrowing from central banks. However, central bank borrowing typically requires high-quality collateral, commonly government bonds, which are low-risk assets. As a result, commercial banks, to meet these collateral requirements and maintain access to central bank liquidity facilities, must increase their holdings of government securities. Commercial banks reallocate resources away from lending to the private sector in favor of government bonds, reflecting a trade-off between liquidity and profitability. Private sector loans offer higher interest returns compared to government bonds, which are low-risk but hold a low yield. Banks sacrifice higher-margin lending activities by shifting their asset composition toward safer but less profitable securities. Overall, this triggers a compression in bank net interest margins, equal to the difference between the interest rate earned on banks' assets and the interest paid on liabilities. As banks become less profitable, their ability to accumulate retained earnings decreases, exerting downward pressure on bank equity; equity grows at a slower rate. At the same time, banks have to comply with certain ratios regarding capital requirements which limit the amount risk-weighted assets (RWA) banks can hold compared to their equity. Banks are then forced to deleverage—reduce the size or the riskiness of their assets portfolio—to comply with capital adequacy ratios. The tightening in credit supply, resulting from bank deleveraging, could affect negatively real economic activity. The bank

disintermediation could offset the fiscal expansion effect and the overall net steady-state impact of CBDC on real GDP could be negative. In particular, lower investment and consumption financed through credit can dampen aggregate demand.

Figure [3]: [CBDC transmission]

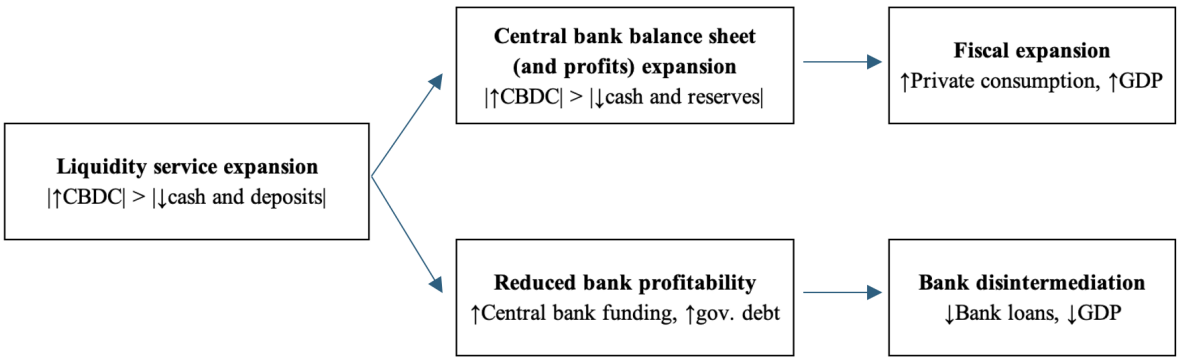


Figure 3 depicts the transmission mechanism of CBDC. To summarize, a liquidity service expansion occurs if the increase in CBDC in circulation outbalances the decrease in cash and deposits. This scenario would lead to two different effects: fiscal expansion and bank disintermediation. If the growth in CBDC exceeds the decline in cash and reserves, central banks balance sheets and profits would expand, leading to an increase in private consumption and GDP; the final outcome would be a fiscal expansion. The other effect resulting from liquidity service expansion could be reduced bank profitability, due to a rise in central bank funding and government debt; this would lead to bank disintermediation with a decrease in bank loans and fall in GDP.

Moreover, the introduction of a CBDC would increase the demand for interest rate hedges, such as interest rate swaps and/or alter banks' supply of loans. Hedging is a risk management strategy to offset losses in investments by taking an opposite position in a related asset. Most retail deposits are non-maturing: there is no fixed maturity and people can withdraw them any time. In practice people tend to leave money deposited in the bank even when interest rate changes and behavioural models estimate these deposits as having a long average

duration[33]. Banks treat these deposits as long-term funding, even though technically they are short-term liabilities. This allows banks to match them against long-term, fixed-rate assets, creating a natural hedge[34]. When interest rates rise, the cost of deposits increases only gradually due to the slow adjustment of deposit rates, while income from loans increases more rapidly, benefiting banks. With the introduction of CBDC, households would remove money from bank deposits, inducing banks to lose these sticky, low cost deposits. Not relying on natural hedges, banks are forced to use other financial instruments to hedge interest rate risk, especially interest rate swaps – to exchange fixed and floating rate payments– or modify their supply offer, reducing long-term fixed-rate loans in favor of floating-rate loans.

2.2 Influences of a CBDC on Run Dynamics of Financial Institutions

Financial institutions perform liquidity transformation, funding illiquid assets with liabilities that are callable on demand, which makes them vulnerable to runs. The introduction of a central bank digital currency (CBDC) creates a new option for depositors in times of stress and thus can alter traditional run dynamics. Key mechanisms through which a CBDC might influence run risk include:

- Safe-Haven Flight: A CBDC provides an attractive flight-to-safety option for depositors during crises. Because a CBDC represents a direct claim on the central bank, it is perceived as safer than bank deposits and is easier to obtain than cash. As a result, anxious depositors could rapidly shift funds into CBDC, intensifying run risk for banks and other intermediaries. The convenience and low switching costs of moving into CBDC, especially if it offers payment utility and even interest, further increase its appeal as a safe haven during panic episodes.
- Funding Structure Shifts: Over time, widespread CBDC adoption could lead to a permanent re-composition of bank funding. If customers prefer holding CBDC to uninsured deposits, banks may lose stable retail deposits and become more reliant on wholesale funding or other short-term sources. Wholesale funds are typically more flighty and sensitive to market conditions; thus, a banking system funded with a higher share of such liabilities would be more susceptible to runs under stress. In other words, the presence of CBDC can indirectly

[33] Driscoll and Judson (2013)
[34] Drechsler et al. (2021)

increase structural liquidity risk by eroding the stable deposit base that banks normally count on.

- Information and Monitoring: Because CBDC transactions are recorded digitally by the central bank, they could give policymakers real-time insight into depositors' behavior during a panic. Sudden surges in CBDC conversions (digital withdrawals) could serve as an early warning indicator of a bank run in progress. This improved transparency might enable regulators to respond more swiftly (for instance, by providing emergency liquidity or calming communications), potentially dampening the severity of runs.

In sum, a readily accessible CBDC introduces a new dynamic where deposits can flee to the safety of the central bank's digital liability, potentially accelerating runs, even as it offers tools that could improve crisis liquidity management and monitoring. Policymakers therefore stress careful CBDC design (e.g. tiered interest or holding limits) to balance the benefits of a digital safe asset against its financial stability risks[35].

2.3 Implications of CBDC for Credit Provision by Banks in Crisis

A widely adopted CBDC could also affect banks' ability to supply credit, especially during financial crises. In normal conditions, banks use deposits (a relatively low-cost funding source) to fund loans. But if a significant share of deposits shifts into CBDC banks might be forced to replace lost funding with more expensive or volatile sources. This rise in funding costs would squeeze banks' net interest margins and likely compel them to decrease lending or raise loan interest rates, with negative consequences for credit provision across the economy. In essence, a digital euro that competes with deposits could, under stress, constrain banks' balance-sheet capacity to lend, thereby amplifying a credit crunch when funding is most needed. The outcome would be lower liquidity insurance for the private sector and heightened instability, as companies find it harder to obtain cash when markets are stressed.

The degree of credit disintermediation due to CBDC ultimately hinges on the scale and speed of CBDC adoption and on policy responses. If CBDC uptake remains small or grows gradually, banks could adjust by retaining higher liquidity buffers or securing backstop funding, thus limiting the credit

[35] Ahneret et al. (2023)

impact. By contrast, a rapid large-scale migration of deposits to CBDC (possibly spurred by network effects or panic) would pose a more serious challenge. Initial conditions are critical: banks entering a crisis with abundant excess reserves and strong capital could better weather deposit outflows, whereas those already strained would need to cut assets (loans) more sharply. Moreover, central banks can mitigate credit supply shocks by acting as lenders of last resort – for instance, by expanding emergency lending facilities or loosening collateral rules to support banks that lose funding to CBDC[36]. Such measures can replace some of the funding that vanished into CBDC and help sustain lending in the economy. However, these interventions are not without limits or risks, and they underscore the trade-off: introducing a CBDC may necessitate a more robust safety net to prevent undue harm to credit creation during crises. In summary, while a digital euro could enhance payments resilience, it may also inadvertently reduce bank lending capacity in turmoil, unless carefully managed through both prudent bank policies and supportive central bank actions.

2.4 CBDC's Role in Addressing Financial Stability Risks from Stablecoins

The rise of stablecoins in the crypto-asset market has introduced new financial stability concerns. Stablecoins are privately issued digital tokens designed to maintain a stable value (typically pegged to a national currency like the euro or dollar). They facilitate quick trading and act as a bridge between traditional money and cryptocurrencies. Indeed, stablecoins have become a key source of liquidity and collateral in decentralized finance, offering lower-cost entry and exit into crypto markets[37]. However, despite their name, stablecoins are not risk-free: they have proven prone to runs and losses of peg parity when investors doubt the issuer's ability to redeem them at face value[38].

A well-designed CBDC could mitigate some of these stablecoin-related stability risks. By offering a public digital alternative with full central bank backing, a CBDC might reduce the demand for privately issued stablecoins that carry credit or liquidity risks. For example, users seeking a digital euro for payments or savings would likely prefer the zero-credit-risk CBDC over a corporate-issued stablecoin, especially during times of stress. This substitution effect would shrink the scale of unstable stablecoin liabilities in the financial system. Furthermore, a CBDC can improve the quality of stablecoins' reserve assets: stablecoin issuers, if permitted, could hold CBDC as their reserve backing.

[36] Bouis et al. (2024)
[37] Carapella et al. (2024)
[38] Gorton et al. (2022-fprse2023?)

Since a digital euro is a direct claim on the central bank, a stablecoin fully backed 1:1 by CBDC would be much safer and less likely to break its peg under duress. In essence, such an arrangement turns stablecoins into transparent "wrappers" of central bank money, eliminating traditional run triggers related to reserve adequacy. Some scholars argue that this could shift competition among stablecoins away from risky promises of convertibility and towards technological features or efficiency, thereby improving the resilience of the digital asset ecosystem. Enhanced transparency could arise as well: if stablecoin reserves are held in CBDC on a public ledger, it becomes easier for regulators (and even the public) to verify that each token is fully backed in real time, reducing uncertainty about their solvency.

However, a CBDC is not a solution for all stablecoin risks. Stablecoins exist to serve various functions, some of which might lie outside the scope of a retail CBDC's design or legal framework. For instance, certain stablecoins facilitate decentralized finance transactions, cross-border transfers, or offer privacy features that a centrally issued digital euro may not provide. Those stablecoins serving niche demands (especially in jurisdictions without a CBDC, or in unregulated contexts) would likely continue to operate and could still pose stability risks. In fact, if a CBDC is only accessible domestically or comes with usage constraints, crypto-market participants might still resort to private USD-pegged stablecoins for global trading or as collateral in offshore platforms. Moreover, while a CBDC-backed reserve model makes stablecoins safer, it introduces regulatory and operational challenges – central banks would need to decide which institutions can swap reserves for CBDC and under what conditions, and they would assume a greater role in the functioning of what are currently private monies. Legal, custodial, and cybersecurity issues would also persist; a stablecoin fully backed by CBDC could still face technical failures or hacks that undermine confidence, issues a CBDC itself would have to be designed to withstand.

In summary, the introduction of a digital euro could significantly enhance financial stability by curbing the growth of risky stablecoins and bolstering those that remain with superior backing. By providing a risk-free digital settlement asset, a CBDC can absorb functions that might otherwise be served by less stable private substitutes, thereby reducing the likelihood of destabilizing runs in the crypto-financial realm[39]. Nonetheless, authorities recognize that some stablecoins may thrive in niches beyond the CBDC's reach, meaning a parallel effort in regulating and supervising stablecoin arrangements is necessary. A combination of a strong public alternative (CBDC) and appropriate

[39] Azar et al. (2022)

regulation for residual stablecoin activities would together address the financial stability challenges posed by the advent of digital currencies in both the traditional and crypto domains.

Chapter III. CBDC Implications for Banks' Balance Sheets

This chapter analyzes how the introduction of a Central Bank Digital Currency, specifically the digital euro, could reshape the balance sheets of both commercial banks and the central bank (ECB). Section 3.1 outlines the structure of modern central bank and commercial bank balance sheets. Section 3.2 explores potential adjustment strategies that commercial banks might adopt in response to deposit outflows caused by CBDC adoption. It evaluates the trade-offs of each strategy in terms of liquidity, profitability, and regulatory compliance. Section 3.3 investigates how these adjustments influence the overall size and structure of commercial bank and central bank balance sheets.

3.1 Central Bank and Commercial Banks' Balance Sheets

This section offers a comprehensive description of the operations of a contemporary monetary system. To analyse the effect of the digital euro on commercial banks and central banks it is essential to outline the main features of their balance sheets.
Figure 4 illustrates the components of a commercial bank's balance sheet.

Figure [4]: [Commercial Bank balance sheet]

Commercial Bank	
Assets	**Liabilities**
Banknotes	CB loans
CB reserves	Bank loans
Securities	Overnight deposits
Loans	Other ST deposits
Derivatives	Bonds & LT deposits
Other assets	Other liabilities
	Net Worth

The asset side indicates the uses of funding by the bank. Commercial Bank assets include: cash, bank reserves, securities, loans, derivatives, real assets/property and other assets. Cash items and liquid reserves are deposited with the Central Bank: cash is acquired from central

banks and distributed to commercial banks, while bank reserves are for interbank payments. Liquid reserves are equal to Required reserves (R.R.) plus Voluntary reserves (V.R.). Securities provide a connection with financial markets, they comprehend government securities and corporate bonds. Commercial banks use bank reserves to settle interbank payments and to meet their customers' demand for cash. The main types of government securities are Treasury bills, notes and bonds; Municipal bonds and SN bonds. Loans represent a connection with banks, businesses and households. Commercial banks engage in various lending activities, including interbank loans and consumer loans. They also extend commercial loans (typically short-term) and industrial loans (typically long-term). Additionally, they provide long-term financing for real estate purposes. Derivatives– such as forwards, futures, options and swaps– provide a connection with financial markets, they are used for risk hedging purposes and speculative purposes. Real assets concern gold, works of art, real estate (including premises) and other assets.

Bank assets generate interest, dividends, and returns, which are recorded on the revenue side of the bank's income statement, along with income derived from off-balance sheet activities. The returns on assets typically vary inversely with liquidity and directly with risk. Liquid assets have a low risk profile, they slightly impact prudential capital requirements and have a high flexibility in reallocating resources across asset classes. On the other side, liquid assets have a lower profitability compared to illiquid assets due to reduced yields. Bank assets can be distinguished according to their maturity, liquidity and riskiness. Cash and bank reserves are very liquid, very safe and yield no interest. Securities have varying degrees of liquidity and they are subject mainly to market risk, for example risk of depreciation in nominal terms but they are also subject to interest rate risk, and default risk. Securities are interest bearing as a compensation against risk. Loans are illiquid especially if medium to long-run maturity, unless the bank resorts to securitization; they are risky and exposed mainly to credit risk; they are interest-bearing.

The liability side indicates different sources of funding. The bank liabilities are borrowing, deposits, bank bonds, bank hybrid securities and non-interest bearing liabilities. Bank borrowings consist of loans obtained from the central bank through refinancing operations and loans sourced from other financial institutions via the interbank market. Different types

of deposits exist: current account deposits, saving deposits and time deposits (Certificates of deposit).

Bank liabilities can be classified according to their time dimension and maturity. Liabilities can be short, medium or long-term liabilities and their maturity can be pre-determined or they are redeemable on demand or at notice. Banks pay interest or dividends on various funding sources, which are recorded on the cost side of the bank income statement. According to the relationship between interest rate and liquidity premium, short-term liabilities typically have lower interest rates than long-term ones. Banks often pay little or no interest on liquid liabilities, they are a cheaper funding source than less liquid liabilities. At the same time the supply of liquid assets is more volatile: depositors can withdraw money at any time and banks cannot control the timing or volume of outflows. Banks benefit from the low cost of liquid liabilities but face greater volatility and liquidity risk. Using fewer liquid liabilities increases stability, but at a higher cost.

Net worth represents the capital owned by the bank. It is equal to the sum of the equity capital (Shareholders' initial capital), retained earnings (new capital recapitalisation) and reserves against risk.

Turning to the central bank's balance sheet, Figure 5 illustrates the composition of its assets and liabilities.

Figure [5]: [Central Bank balance sheet]

Central Bank	
Assets	**Liabilities**
Gold	Banknotes
CB loans	CB reserves
Securities	Other liabilities
Other assets	
	Net worth

Central bank balance sheet provides insights into its core operations. Central Banks assets include gold and gold receivables, foreign assets, government balances, Central banks operations, loans, securities and other items. Central banks hold physical gold as a reserve

asset, it serves as a store of value and a hedge against inflation or currency depreciation. Gold receivables are claims on gold held elsewhere, often related to gold loans, swaps, or deposits with other institutions. Foreign assets include foreign currencies, foreign securities (typically government bonds), and deposits with foreign banks. These are used to intervene in foreign exchange markets, manage currency stability, and provide liquidity in times of crisis. Government balances are deposits that the central government keeps at the central bank, they reflect the Treasury's current cash position and can influence liquidity in the banking system. Central bank operations refer to assets that are created through monetary policy instruments, including open market operations, liquidity provision to financial institutions, and asset purchase programs such as quantitative easing.

The liabilities of a central bank include banknotes, reserves and other liabilities. Banknotes are recorded as liabilities because, despite being issued by the central bank, they represent an obligation to provide value in exchange. The central bank issues bank reserves by extending loans to commercial banks (against collateral) and by buying assets from commercial banks.

3.2 Adjustment Strategies to Deposit Substitution by CBDC

In the paper "CBDC and the Banking System"[40] the authors analyse the impact of CBDC on credit institutions' balance sheets in response to the outflow of deposits caused by the substitution of private money with public digital money, using data on Italian banks between June 2021 and March 2023. The framework is based on two simplifying assumptions: (1) banks have no market power, hence CBDC would have no influence on bank's pricing decisions. By assuming a mechanical (fixed) outflow of deposits, the authors isolate the pure impact of a CBDC on banks' funding and balance sheets without the complication of strategic responses by banks. (2) The simulations ignore potential developments in the payments landscape, such as the rise of private digital money; any observed effects in the model can be attributed solely to the introduction of the CBDC, not to broader digital payment trends.

Banks can combine multiple adjustment strategies to respond to the decline in deposits.

[40] Auer et al. (2024)

Figure [6]: [Adjustment strategies to bank deposits outflow]

Adjustment strategy	**Instruments**	**Net stable funding**	**Liquidity**	**Asset encumbrance**	**Net interest income**	**Size**
Increase short-term liabilities	Repos, ST CB refinancing	-	-	+	≈	≈
Increase long-term liabilities	Bonds, LT CB refinancing	≈	≈	+ (unless un-secured bond)	- (if bonds) ≃ (if CB)	≈
decrease short-term assets	CB reserves, Repos, ST securities/loans	≈	-	+	≈	-
decrease long-term assets	Loans, LT securities	+	+ (if loans) - (if HQLA securities)	+	-	-

Note: the symbol of approximation ≈ is used when the final effect is modest and its sign depends on factors usually estimated by banks via behavioural models.

In figure 6 adjustment strategies to bank deposits outflow are listed. For each strategy, the table summarizes the expected impact on key prudential metrics and balance sheet characteristics.

The metrics used to measure the consequences of the instruments adopted encompass NSFR, LCR, asset encumbrance, net interest income and size of the balance sheet.

- Net Stable funding ratio (NSFR) measures whether a bank has enough stable, long-term funding to support its long-term assets. It is equal to the ratio between available stable funding and required stable funding and it has to be greater than 100% to reduce the risk of a liquidity crunch over a 1-year horizon.
- Liquidity Coverage Ratio (LCR) requires banks to hold enough high-quality liquid assets (HQLA) to survive a 30-day stress scenario of cash outflows to ensure banks can meet short-term obligations during times of financial stress. It is calculated as the ratio of HQLA over the total net cash outflow over the next 30 days.

- Asset encumbrance refers to the portion of a bank's assets that are pledged as collateral and therefore not freely available for other uses. Encumbered assets can't be quickly sold or reused in a crisis and high encumbrance reduces a bank's flexibility and resilience.
- Net interest income is the difference between interest earned on assets and interest paid on liabilities. NII is the main source of income for traditional banks and a lower NII usually means lower profitability, unless offset by fee income.
- Size of the balance sheet refers to the total value of a bank's assets or liabilities. If a bank borrows money and lends it out, size increases, while if it pays off loans or sells assets without replacing them, size decreases. A larger balance sheet often means a bigger, more active bank, but it also may mean greater systemic risk.

This framework helps identify the trade-offs banks face when selecting between instruments such as short or long-term funding or adjusting their asset holdings. The four main strategies identified in this paper are the increase in short-term long liabilities, increase in long-term long liabilities, decrease in short-term assets and decrease in long-term assets.

1. Increase in Short-term Liabilities – it consists in raising funds through wholesale repos or short-term refinancing operations with the central bank (Main Refinancing Operations–MROs). These are quick sources of funding, but also relatively less stable than deposits; therefore NSFR falls while the effect on LCR is uncertain. On one hand, central bank fundings are considered more reliable than deposits, meaning that the expected cash outflows may be lower when a bank uses CB funding instead of deposits; this results in a lower denominator. On the other hand, to obtain central bank loans, banks often have to pledge HQLA as collateral and these assets can't be counted in the numerator of the LCR anymore. The fall in both numerator and denominator has a mixed effect on LCR and the net impact depends on which effect is stronger. Instead, the overall size of banks' balance sheet remains unchanged, while net interest income depends on the difference between CB funding rate and deposit rate. The impact on NII depends on the interest rate environment: if the CB funding rate is low and close to zero, the impact on NII is minor, while if CB funding rate is

higher the cost increase is higher and it results in a strong negative impact on NII. Asset encumbrance increases, because the bank has to pledge more assets to get short-term funding.
2. Increase in Long-Term Liabilities – issuance of long-term bonds or borrowings from the central bank via Long-Term Refinancing Operations (LTROs). The two instruments differ in terms of funding costs, with central bank operations usually being more favourable. These long-term funding sources are considered stable under regulatory frameworks, like retail deposits; therefore Net Stable Funding Ratio (NSFR) remains unchanged. Liquidity Coverage ratio stays stable as well. Diversely, asset encumbrance increases because bonds and central bank LTROs require collateral as guarantee, tying up assets more than in the case of short-term liabilities. Asset encumbrance does not increase in the case of unsecured bonds. Net interest income decreases if the bank issues bonds, while it remains unchanged if it borrows from the CB. The overall size of the balance sheet does not change either.
3. Decrease in Short-term Assets – To offset deposit outflows caused by the introduction of a CBDC, banks can respond by reducing short-term assets such as: Central bank reserves, Repos, Short-term securities and Short-term loans. This frees up cash to match the outflow without needing new borrowing. The balance sheet size shrinks – fewer liabilities (deposits) and assets. Lower High-Quality Liquid Assets (HQLA) results in a lower numerator in the LCR. This weakens the bank's ability to survive a 30-day stress scenario. The NSFR has worsened due to a lower proportion of stable liabilities and an increase in short-term assets on the balance sheet. When a bank has fewer freely available assets, it becomes harder to pledge collateral or react to future liquidity needs – asset encumbrance increases. If reserves have negative yields, removing them improves profits. If the spread between interest on short-term assets vs. cost of deposits is small, then selling them has little effect. Therefore Net interest income may increase slightly, or remain stable, depending on interest rate conditions.
4. Decrease in Long-Term Assets – Banks can liquidate assets with an analogous maturity of retail deposits. This reduces the size of the balance sheet and helps rebalance funding and asset maturity. Selling long-term assets lowers the Required Stable Funding (denominator of the NSFR), improving funding stability metrics. Long-term assets have a required stable funding factor equal to 100%, while retail deposits have an available stable funding factor

equal to 90-95%. Therefore, removing the same amount from both the numerator and the denominator, the denominator drops more than the numerator and the NSFR ratio increases. As long-term assets generally earn a higher interest rate compared to retail deposits and other short-term liabilities, the medium-term impact on the net interest income would be negative, NII drops over time as well as profits. This effect is particularly evident if the bank reduces the stock of long-term loans (e.g. via securitization). The liquidity impact depends on the composition of what the bank chooses to sell. If the bank removes from its balance sheet private loans the bank's liquidity ratios would improve as illiquid loans are removed, improving the quality of the asset base. Conversely, a reduction in government bonds would result in a loss of liquid assets, reducing the numerator of the LCR and worsening the liquidity ratio. This strategy is a double-edged sword because it strengthens regulatory ratios (NSFR, sometimes LCR), but it weakens profitability (NII) and shrinks the bank.

3.3 Adjustment Strategies and Impact on Balance Sheets

Depending on the adjustment measures used by commercial banks in response to bank deposit outflows, this paragraph outlines the potential impacts on the central bank's and the banking industry's balance sheets.

1. If banks finance the reduction in deposits with short-term liabilities, raising funds through refinancing operations with the central bank, the aggregate balance sheet of the banking system and of the central bank would change.

Figure [7]: [Increase in Short-term Liabilities]

(a) Step 1: the commercial bank obtains CBDC through refinancing operations

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		**CB loans**	+	Gold		Banknotes	
CB reserves		Bank loans		**CB loans**	+	CB reserves	
Securities		Overnight deposits		Securities		Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets		Other liabilities					
CBDC	+						
Total	+	***Total***	+	***Total***	+	***Total***	+

(b) Step 2: the commercial bank provides CBDC in exchange for deposits

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		**CB loans**	+	Gold		Banknotes	
CB reserves		Bank loans		**CB loans**	+	CB reserves	
Securities		**Overnight deposits**	-	Securities		Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets		Other liabilities					
CBDC							
Total		*Total*		***Total***	+	***Total***	+

Notes: ST and LT deposits stand for "short-term deposits" and "long-term deposits" respectively. Balance sheet items that increase with respect to Figure 4 and Figure 5 are in green; those that decrease are in red. The variation in balance sheet items is defined relative to the initial equilibrium. Entities in bold indicate items directly affected by the reduction of deposits.

Sources: Auer et al. (2024).

As illustrated in figure 7, the operation is divided in two different steps: first commercial banks obtain CBDC through refinancing operations, and then the banking sector provides CBDC in exchange for deposits. When receiving the CBDC we observe the following changes on the commercial bank balance sheet: on the asset side CBDC increases, while on the liabilities side CB loans increase. In the transaction central bank assets (CB loans) increase and central banks liabilities (CBDC) increases simultaneously. When the CBDC is provided to households and firms, for commercial banks, only the balance sheet composition is different: on the liability side overnight deposits decrease and CB loans increase by the same amount. For the central bank balance sheet also its size changes: assets (CB loans) and

liabilities (CBDC) increase. In the first step the total size of the balance sheet of the banking sector and central bank increases; in the second step the size of the banking sector size turns to its original dimension while the central bank balance sheet increases compared to initial level.

2. Banks may finance the reduction in deposits with long-term liabilities, issuing covered bonds purchased by the central bank.

Figure [8]: [Increase in Long-Term Liabilities]

(a) Step 1: the commercial bank obtains CBDC through bond issuance

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves		Bank loans		CB loans		CB reserves	
Securities		Overnight deposits		**Securities**	+	Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		**Bonds & LT deposits**	+				
Other assets		Other liabilities					
CBDC	+						
Total	+	***Total***	+	***Total***	+	***Total***	+

(b) Step 2: the commercial bank provides CBDC in exchange for deposits

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves		Bank loans		CB loans		CB reserves	
Securities		**Overnight deposits**	-	**Securities**	+	Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		**Bonds & LT deposits**	+				
Other assets		Other liabilities					
CBDC							
Total		*Total*		***Total***	+	***Total***	+

Sources: Auer et al. (2024).

In figure 8 it is shown how the banking sector first obtains CBDC through bond issuance and then it provides CBDC in exchange for deposits. In the first step, the banking system issues bonds, which are purchased by the CB in exchange for CBDC. Banks' balance sheets undergo an expansion in size: an increase in CBDC (assets) is matched by an equal increase in bonds & long-term deposits (liabilities). In the transaction, central bank assets and liabilities

increase simultaneously– securities and CBDC increase. When the banking sector provides CBDC in exchange for deposits, overnight deposits decrease and bonds and long-term deposits increase. For the central bank balance sheet its size changes: assets (securities) and liabilities (CBDC) increase. In the first step the total size of the balance sheet of the banking sector and central bank increases; in the second step the size of the banking sector size turns to its original dimension while the central bank balance sheet increases compared to initial level.

3. Banks may finance the reduction of deposits with a decrease in reserves and other short-term assets.

Figure [9]: [Decrease in Short-term Assets]

(a) Step 1: the commercial bank obtains CBDC by selling reserves and other short-term assets to the central bank

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves	-	Bank loans		CB loans		**CB reserves**	-
Securities		Overnight deposits		Securities		Other liabilities	
Loans		Other ST deposits		**Other assets**	+	**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets	-	Other liabilities					
CBDC	+						
Total		*Total*		***Total***	+	***Total***	+

(b) Step 2: the commercial bank provides CBDC in exchange for deposits

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves	-	Bank loans		CB loans		**CB reserves**	-
Securities		**Overnight deposits**	-	Securities		Other liabilities	
Loans		Other ST deposits		**Other assets**	+	**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets	-	Other liabilities					
CBDC							
Total	-	***Total***	-	**Total**	+	**Total**	+

Sources: Auer et al. (2024).

Figure 9 illustrates the two steps of the transaction: the banking sector obtains CBDC by selling reserves and other short-term assets to the central bank and then it provides CBDC in exchange for deposits. In the first step, on the liability side of a bank balance sheet CB reserves and other assets decrease, matched by an equal increase in CBDC. Central bank assets increase, CB reserves decrease but less than the increase in CBDC. When banks provide CBDC in exchange for deposits, compared to the initial level, CB reserves and other assets decrease, as well as overnight deposits. In the second step Central bank assets increase, CB reserves decrease but less than the increase in CBDC. In both steps the size of the central bank balance sheet increases, while when banks sell reserves and other short-term assets, the bank balance sheet size remains unchanged. When the banking sector provides CBDC in exchange for deposits, the total size of the balance sheet decreases.

4. Banks may liquidate long-term assets to finance the reduction of deposits.

Figure [10]: [Decrease in Long-Term Assets]

(a) Step 1: the commercial bank obtains CBDC by reducing long-term assets

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves		Bank loans		CB loans		CB reserves	
Securities	-	Overnight deposits		**Securities**	+	Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets		Other liabilities					
CBDC	+						
Total		*Total*		***Total***	+	***Total***	+

(b) Step 2: the commercial bank provides CBDC in exchange for deposits

Commercial Bank				Central Bank			
Assets		**Liabilities**		**Assets**		**Liabilities**	
Banknotes		CB loans		Gold		Banknotes	
CB reserves		Bank loans		CB loans		CB reserves	
Securities	-	**Overnight deposits**	-	**Securities**	+	Other liabilities	
Loans		Other ST deposits		Other assets		**CBDC**	+
Derivatives		Bonds & LT deposits					
Other assets		Other liabilities					
CBDC							
Total	-	***Total***	-	***Total***	+	***Total***	+

Sources: Auer et al. (2024).

As depicted in figure 10, the transaction is divided in two steps: first the banking sector obtains CBDC by reducing long-term assets and then it provides CBDC in exchange for deposits. In the first step, on the assets side of the bank balance sheet, securities decrease by the same amount of the increase in CBDC. In the central bank balance sheet securities (assets) increase and CBDC (liabilities) increase as well. When the banking sector provides CBDC in exchange for deposits, securities (assets) on the commercial bank balance sheet fall compared to the initial level. Overnight deposits (liabilities for the bank) fall too. For the central bank, securities (assets) and CBDC (liabilities) increase. The size of the bank balance sheet in the first step is unchanged, while the central bank balance sheet expanded. In the second step the bank balance sheet shrinked and the central bank balance sheet expanded.

According to the paper "CBDC and the Banking System" [41] the impact of the conversion from retail bank deposits into CBDC is manageable if CBDC adoption is modest. The effects on banks' funding structures (how they raise money to lend or invest) would be relatively small if the take-up (and deposit substitution) is less than 15% of retail deposits. The threshold is obtained through a series of exercises performed on Italian banks in normal times on the impact of a CBDC on the funding structure and profitability, using data from June 2021 to March 2023. Banks could adjust without major issues, especially if the CBDC design includes individual holding limits and if the banking system is particularly liquid (cash or easily accessible funds). Larger CBDC adoption increases risks, especially without holding limits. Banks could lose a significant source of stable funding, and this would be particularly problematic if the banking system already has low liquidity. Profitability impact depends on the size of the deposit outflow, which is determined by CBDC demand. If CBDC demand is low banks would experience similar (modest) reductions in profitability across the board. Instead if the CBDC demand is high the effects would vary more across banks. Some might cope better, others worse, depending on their specific situations. The most affected banks are those with low excess reserves (limited buffer funds) and those that would have to issue long-term debt, which is more expensive, to maintain their Net Stable Funding Ratio (NSFR),

[41] Auer et al. (2024)

ensuring reliable funding. These banks would face higher funding costs, making it more expensive to replace the lost deposits and potentially reducing their profits.

Conclusions

The primary rationale of CBDCs is to preserve central bank money's role by offering the public a digital form of legal tender. The Eurosystem would issue the digital euro, while supervised intermediaries (e.g. banks and payment service providers) distribute it and manage customer interactions, leveraging existing financial infrastructure. The digital euro is designed to complement, not replace, physical cash, providing a universally accepted and risk-free payment medium across the euro area. It promises a secure means of payment for the digital age while fostering innovation and financial inclusion. Transactions are envisioned to be instantaneous and secure, operable online or offline. Importantly, the design includes safeguards such as individual holding limits (on the order of a few thousand euros per person) and automated "waterfall" transfer mechanisms to prevent excessive outflows from bank deposits into digital euros. These measures ensure the digital euro remains a means of payment rather than a store of value.

The analysis suggests that a digital euro could be introduced in the euro area without endangering financial stability, as long as it is carefully designed and complemented by appropriate policies. Under baseline scenarios – when CBDC take-up is modest, the banking system has a normal amount of liquidity, individual holding limits are present on CBDC and banks maintain their regulatory liquidity buffers – only a moderate portion of bank deposits is likely to shift into CBDC, a change that banks and the central bank can accommodate through adjustments in funding and balance sheet operations. However, in periods of financial stress the availability of a risk-free central bank digital currency could intensify deposit out-flow from banks, potentially accelerating bank runs if no safeguards are in place. This finding underlines the importance of implementing measures such as holding limits. With such measures, even in adverse scenarios, the systemic impact of deposit migration to CBDC can be contained.

In terms of banks' balance sheets, the introduction of a digital euro would primarily reduce banks' reliance on retail deposit funding. This disintermediation could modestly compress banks' net interest margins and profitability, as banks replace lost deposits with more

expensive or less stable sources of funding, as wholesale repos or refinancing operations with the central bank (MROs and LTROs). Otherwise, banks to offset deposit outflows can respond by reducing assets as central bank reserves, repos, securities and loans. In essence, a digital euro may tilt the banking sector's funding mix toward more central bank and market funding. Crucially, banks are not passive actors and can adapt their strategies to the new environment. They could compete to retain deposits by offering improved services to depositors, although this may erode some profits. Banks can also leverage their role as intermediaries in the digital euro system by providing digital euro wallets, payment apps, and other value-added services to customers. By embracing such opportunities, banks might develop new revenue streams or at least preserve customer relationships despite the presence of CBDC. Additionally, banks can become more efficient, for example by reducing costs associated with physical cash handling.

Looking beyond the banking sector, a widely adopted digital euro would carry broader implications for monetary policy and financial regulation. On one hand, a CBDC could enhance monetary policy transmission by giving the central bank a more direct influence on retail liquidity conditions. On the other hand, monetary authorities would need to carefully calibrate CBDC design features to avoid unintended consequences for monetary control or market interest rates. Ensuring robust data privacy and cybersecurity standards for the digital euro ecosystem will be another critical regulatory task, though these issues lie outside the immediate scope of this thesis.

To conclude, CBDCs represent a significant innovation in the monetary landscape. With prudent design and policy coordination, it can modernize payments and complement the banking system without undermining financial stability.

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