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Chapter 4

Dear Readers,

we are pleased to present this year's latest issue of the Argo Collection which projects us towards a 2024 full of new challenges and changes, especially when talking about Central Bank Digital Currencies (CBDC). The issue of the Digital Euro in Europe is under the spotlight not only of central banks, but also of commercial banks which will have to deal with the request for a significant technological improvement to offer services linked to the use of digital currencies.

This edition seeks to set out in clear detail the aspects, implications and risks associated with the adoption of the digital Euro as a currency that will circulate alongside cash, as stated in the European Central Bank's latest October press release on CBDC.
During the drafting of the monograph, the authors thought to provide the reader with a key to reading that links the chapters in a consequential way and that follows step by step the paradigm of the circulation of money starting from the origin, the central banks that issue, to the final retail customers who use it.
The introductory chapter provides a definition of CBDC with particular emphasis on the Digital Euro, from the point of view of financial stability, examining in the current macroeconomic context, how monetary policies can impact the entire economy. Financial stability is the main building block that justifies the presence of a digital currency as a mean to improve the complex infrastructure of the financial system based on payments, transfer of resources and risk management, while monetary policies implemented by central banks represent the tool to regulate it.
The effectiveness of CBDCs is closely related to the structure of the financial system and the operational framework of central banks. For this reason, chapter two discusses design models for the newly created central bank digital currencies that facilitate the coexistence and seamless integration with physical money into the economic fabric.
In addition to the central bank, we will see in the third chapter how, even commercial banks and intermediaries, play a fundamental role in the challenge of the digital euro because they will find themselves with the burden of managing the entire economic framework and technological infrastructure to enable the offer and circulation of the digital currencies, between wholesale and retail customers. Through the introduction of new payment systems, commercial banks and intermediaries must guarantee challenging standards and tight requirements. The authors emphasize that the CBDC architecture will need to be carefully designed to address the potential risks and challenges, such as security, privacy, and cross-border payments.
In the last chapter, attention will be focused on the ways of using digital currencies and on the risks that the tools that will be made available to customers, intermediaries and central banks may imply. The article will not lack parallelisms and references to the other world economies as the United States and China, consider-

ing the state of progress of the projects and experiments on CBDCs with the aim of providing as much as possible a general overview of the echo that these digital currencies are having on a global level. They also note that the CBDC system will need to be compatible with existing financial systems and regulations.

We conclude with a suggestion to visit our online Research page and subscribe to our newsletter service with a monthly update on the most relevant topics about practical Risk Management.

We would also like to take this opportunity to wish you all happy holidays and all the best for the coming year.

We wish you a happy reading!

Luca Olivo
Giulia Perfetti
Gianmarco Mori

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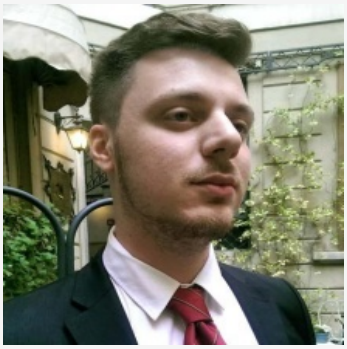

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This document was prepared in collaboration with Nicola Mazzoni and Chiara Stabellini, who at the time were working for Iason Consulting.

CBDCs: Financial Stability and Monetary Policy

CBDCs: Financial Stability and Monetary Policy Implications

Central Bank Digital Currencies (CBDCs), a digital form of a country's official currency, issued and regulated by the central bank, have emerged as a topic of significant interest in the last years. This innovation could, if poorly designed, raise various implications for monetary policy and financial stability. One of the key aspects to consider is how CBDCs might impact the traditional tools of monetary policy to regulate money supply, interest rates, and inflation. The introduction of CBDCs could influence these mechanisms, altering the effectiveness of policies aimed at stabilizing the economy. Furthermore, CBDCs may have implications for financial stability. While they offer the potential for more secure and efficient transactions, their widespread adoption could disrupt the banking sector. Commercial banks might face challenges in attracting deposits, leading to changes in their lending capacities. This shift could impact credit availability and interest rates, influencing economic stability in stressed periods. In this evolving landscape, central banks are tasked with balancing innovation and stability. Striking the right balance is essential to harness the benefits of CBDCs while mitigating potential risks to monetary policy frameworks and financial systems.

Financial Stability Concerns and Implications on the Banking Sector

During the last decade, there has been an increasing interest towards digital assets and central bank digital currency justified, at least to some extent, by initiatives in the private sector moved by distributed ledger technologies, moreover, the decline in cash usage [18] induced Central Banks to assess their role in the financial system. In this sense, the introduction of central bank digital currencies could have sensible impacts on the financial sector both improving the resilience of the payment system and fostering financial innovation. However, an inappropriate design of this new mean of payment could jeopardize financial stability and potentially influence negatively monetary policy and its transmission mechanism. Moreover, the cross-border use of CBDCs, and thus financial transaction that involves the transfer of funds from an individual, company, or financial institution located in one country to a beneficiary located in another country, should be taken into consideration due to the possible impact on both the issuing and recipient country.

Firstly, a Central Bank Digital Currency (CBDC) has the potential to alleviate financial frictions in deposit and loan markets, possibly through more competitive pricing of deposits and loans. Secondly, it could enhance the efficiency of retail payment systems, making transactions quicker, safer, and more cost-effective. Moreover, a CBDC could facilitate international transactions and promote financial inclusion among the unbanked population. In addition, amidst the declining use of cash, a CBDC could ensure the availability of a universally accepted payment method that is not reliant on private intermediaries, especially if directly issued and managed by the central bank. Besides, a CBDC might stimulate technological innovations in banking and payments within the private sector. Indeed, some argue that the emergence of private digital assets could necessitate the creation of a publicly issued digital asset to support the stability of new payment platforms. Lastly, a CBDC has the potential to enhance the transmission of monetary policy. However, CBDCs also come with risks, which largely depend on their design features, of which there are many possibilities. A CBDC can be either token-based, akin to physical currencies, or account-based, like bank deposits. It can be directly held by households and nonfinancial firms (referred to as retail CBDC) or intermediated through banks or nonbank financial entities such as fintechs (intermediated CBDC). Access to holding CBDC could be universal or limited to specific groups, such as households and small businesses. The supply of CBDC could be elastic and continuous for eligible parties, or it might be constrained by caps, transfer size limits or transfer frequency restrictions. CBDC demand would probably be influenced by individual users' preference for the following factors over available alternatives at that time, such as cash, bank deposits, e-money, and other tokens:

- Safety perception compared to insured or uninsured options;
- Accessibility and financial inclusion;

- Compatibility and speed in comparison to other payment methods;
- Technological advancements, such as programmability;
- Remuneration;
- Usage expenses;
- Privacy and anonymity features;
- Convenience in transitioning between CBDC and other options.

Crucially, one of the most significant design aspects of a CBDC is whether it offers remuneration, meaning whether CBDC holdings would earn interest and if this interest would be proportional or tiered based on the holding's size. These design choices impact the CBDC's competitiveness in specific markets and the role it might play. For instance, if a CBDC does not offer interest, its utility as a store of value is limited, especially when market interest rates significantly exceed the effective lower bound (ELB) on nominal interest rates. In such situations, CBDC functions similarly to physical cash, and its usage depends on its convenience relative to other cash-like alternatives. Given the possible impact on the banking industry the creation of a CBDC could also affect the stability of the financial system. In broader terms, the competition posed by CBDC for bank deposits could reshape the financial system. It might displace a category of private debt, compelling banks to seek funding from different sources and potentially increasing the fragility of the banking sector. Additionally, the importance of payments and data in social and commercial platforms might reverse the current structure of financial activities.

In order to give a comprehensive overview of financial stability related issues it is necessary to discuss the impact of Central Bank Digital Currencies in normal and market stressed times. In the first case, with normal market conditions the main issue is related to the contraction of bank deposits and the respective increase in other sources of funding; indeed the most discussed risk is linked to bank disintermediation. Central Bank Digital Currencies could certainly pose a competitive challenge to banks for funding, particularly if it offers interest. This scenario might elevate banks' funding expenses and negatively impact their lending activities. How severely disintermediation would impact lending relies on the availability of alternative credit sources for households and businesses. It also, to some extent, hinges on how CBDC is reintroduced into the economy, including the central bank's response to the rise in CBDC on its balance sheet. More in detail, banks currently rely (in large part) on deposits to fund their loans. A widely available CBDC would serve as a closeor, in the case of an interest-bearing CBDC, near-perfectsubstitute for commercial bank money. This substitution effect could reduce the aggregate amount of deposits in the banking system, especially if CBDC was offered without limits on individual holdings. This could in turn increase bank funding expenses, lower bank profitability, reduce credit availability or raise credit costs for households and businesses, constraining the financing of the real economy. Another related topic is that, with the decrease in banking payments activity, also the level of customer information decreases, leading to higher costs linked to asymmetric information. This chain of effects can vary, depending on certain characteristics of the banking sector:

- **Banking Sector Competitiveness** If banks have significant market power in the deposits market, the introduction of a CBDC directly competing with bank deposits might increase deposit rates. However, it might not necessarily lead to a decrease in the quantity of bank deposits and lending.
- **CBDC Remuneration** The impact of CBDC on bank intermediation depends on its interest rate. A high-interest CBDC could lead to bank disintermediation, while a non-interest or low-interest CBDC might have negligible effects on bank activities. An intermediate interest rate on CBDC could even promote bank intermediation, depending on the competitive dynamics of the banking sector. Moreover, if CBDC interest rates are set independently from policy rates, they can act as a deposit rate floor, compelling banks to offer better terms to depositors. This, in turn, reduces monopoly distortions in the banking sector, increasing the deposit supply through higher savings and including unbanked individuals.
- **CBDC Account Limits** Imposing restrictions on the quantity of CBDC that users can hold, transact, or earn interest on could limit the extent of bank disintermediation. Authorities could implement quantity-based safeguards and price-based safeguards to moderate CBDC take-up and usage. Restrictions based on quantity would limit the usage of CBDC by imposing strict caps on transfers and/or holdings of CBDC. These limits can be either stock-based (where central banks restrict the amount of CBDC held by individuals or individual account holders) or flow-based (restrictions on the quantity of CBDC that can be transferred within a specific time frame, such as a day, by an account holder). The extent of these quantity restrictions could be adjusted to align with the typical usage of cash and common household payment needs. Price-based measures (involving interest rates or fees) could discourage the accumulation of CBDC or significant transactions in CBDC (without outright restrictions). Central banks might opt for uncompetitive interest rates on CBDC holdings to discourage its use. Indeed, the remuneration system could be ei-

ther single-tier or multi-tier. In a single-tier system, CBDC holdings would receive a set rate regardless of the amount held. In a two-tier system, holdings up to a specified threshold amount (q1) would yield a particular return (r1); amounts surpassing q1 would receive a lower return (r2 < r1). Central banks would need to determine interest rate applications (such as spot amount or period averages) based on technical capabilities. Additionally, central banks could contemplate imposing fees (either fixed or progressive) on CBDC transfers exceeding a certain amount. A combination of price-based and quantity-based measure could also be efficient.

- **Wholesale Funding** If banks can compensate for lost retail deposits with wholesale funding, CBDC would have a limited impact on lending. This offsetting effect is especially relevant for larger banks.

Conversely, during periods of market turmoil, the introduction of a widely accessible CBDC could heighten the risk of a systemic bank run, either by initially attracting an excess of depositors or by offering a secure and liquid alternative for depositors to turn to. In recent years, the convenience of online cash transfer services, digital currencies, and rapid payment systems has made withdrawing deposits easier. Simultaneously, stricter regulatory measures for banks and enhanced deposit insurance programs in many countries have decreased incentives for both retail and wholesale customers to withdraw funds during times of stress. However, the introduction of a CBDC (or certain new types of private money) could potentially heighten this risk during periods of financial strain. This is because it offers an easily accessible option as a safe asset. The specifics of any potential run would be influenced by the legal and operational framework of the CBDC and its management by banks or other financial service providers. Moreover, apart from traditional banks, CBDCs might replace investments in other low-risk, liquid assets like Money Market Funds (MMFs) and Treasury Bills, causing sudden changes in their funding sources, that is due to the fact that in certain situations, depending on its specific design and the interest rates it offers, the introduction of a CBDC could be an appealing option for individuals who prefer low-risk alternatives to cash substitutes, even under favorable market circumstances. A significant change in the volume of transactions in certain money markets could impact the robustness of vital interest rate benchmarks[26]. Money market activities, particularly overnight unsecured deposit transactions involving MMFs, contribute significantly to the calculation of interest rate benchmarks like SONIA or EONIA. As observed in the past with LIBOR, the accuracy of these indices, which is crucial for the functioning of financial markets, depends on substantial transaction volumes in the underlying markets. Once again, the run risk problem in bank runs models with CBDC is that deposits and CBDC are near-perfect substitutes. Accordingly, the proposed solutions to this problem tend to involve either reducing the substitutability of these assets for some or all financial agents or limiting the range over which substitution can occur. Thus, the instability caused by a systemwide run into CBDC can be mitigated with some of the design features of CBDC. Moreover, for the sake of tackling bank run threats, authorities or intermediaries might implement a crisis management framework involving restrictions on individual holdings or withdrawals to mitigate the risk of abrupt deposit outflows. As an illustration, existing LCR regulations determine outflow parameters for deposits from retail and small business customers by considering observed outflow rates during stress periods. These rates, however, do not factor in the potential influence of CBDC or new private digital currencies on depositor behavior during stressful situations. If the introduction of CBDC elevates outflow risks for these deposits, it might be necessary to reevaluate the corresponding outflow rates. This reassessment is crucial to guarantee sufficient liquidity to cover potential outflows during times of stress.

A View on Monetary Policy Implications of CBDCs

Monetary policy encompasses the measures undertaken by a central bank or monetary authority to regulate the money supply within an economy. These actions are aimed at achieving broader economic goals, including the maintenance of price stability characterized by low and steady inflation and the promotion of sustainable economic growth. The goals and frameworks of monetary policy remain consistent even when countries introduce a CBDC. However, as a novel payment method, CBDCs can bring about alterations in retail, wholesale, and international payments. These changes have significant spillover effects on the implementation and impact of monetary policy.

A retail CBDC represents a new form of currency for everyday transactions by households, while a wholesale CBDC is a modified version of central bank money used for settlements. However, a CBDC plays a significant role in anchoring the broader monetary system, ensuring the central bank continues to offer a reliable payment method that fosters trust in money and transactions. It also affects the cost structure of issuing central bank money and influences seigniorage income, thereby impacting the independence of central banks in conducting monetary policy. Furthermore, CBDCs can trigger changes in retail, wholesale, and cross-border payments, leading to ripple effects on the implementation and impact of monetary policy. Despite being the sole issuer of CBDCs, the central bank lacks con-

trol over public reactions to its issuance and consequently, it does not have complete authority over the liability composition of its balance sheet. Similarly, commercial banks cannot fully dictate the public's preference between deposits and CBDCs as payment methods. The key element is thus to assess if and how can a Central Bank Digital Currency (and its main design options) affect the implementation and transmission of monetary policy. In order to accomplish such task, it is necessary to discern between retail and wholesale CDBC.

Retail CBDC Implications

In the case of a retail CBDC, it could potentially set off a complex network of interconnected reactions, which cumulatively have a harmful impact on the execution and transmission of monetary policy. When introduced as a new payment tool, CBDCs may lead some households and businesses to convert portions of their cash holdings and deposits into CBDCs. If this conversion is substantial, it can alter the public's holdings of cash and deposits, subsequently affecting money velocity, bank disintermediation, and the stability of commercial bank reserves. These outcomes can undermine the effectiveness of money targeting strategies, weaken lending, interest rate mechanisms, and hinder central banks' ability to predict commercial bank reserves, crucial for Open Market Operations (OMO). However, exchanging cash with a retail CBDC would not affect the monetary policy effectiveness via balance sheet as shown in Figure 1; the reason lies in the fact that both physical cash and CBDC are essentially the same thing, that is central bank money and are indeed perfect substitutes.

The composition and size of commercial banks balance sheets remain unchanged, as these banks are limited to an operational role in transferring funds from cash to CBDC. However, exchanging cash for CBDCs can lead to changes in money velocity [27]. Cash transactions involve physical proximity and delays in depositing funds. In contrast, CBDC transactions are digital, allowing remote transfers and immediate crediting. This rapid turnover can increase money velocity and create instability. Instability in money velocity affects the relationship between money, inflation, and GDP and erodes the effectiveness of money targeting regimes (that are built based on a possibly stable relationship between money supply and inflation). Moreover, CBDCs could impact central banks' seigniorage revenues by altering the cost dynamics of issuing currency. They may reduce operational expenses related to physical banknotes but introduce new costs and affect cash demand. Depending on these changes in seigniorage income, central banks might increase or decrease their reliance on government funding, impacting their independence in shaping monetary policy.

Conversely, exchanging banks deposits for CBDCs would have a different effect on monetary policy (Figure 2); funding digital wallets though bank deposits increase the volatility of commercial banks reserves (that in the previous case remained unaffected) and promotes disintermediation [27]. While the latter undermines the effectiveness of the credit and interest rate channels in the monetary policy transmission process, volatility in reserves diminishes central banks' ability to predict reserves accurately and conduct efficient Open Market Operations (OMO).

Additionally, CBDCs stored in digital wallets are recorded on the central bank's ledger and cannot be lent by commercial banks. Assuming other factors remain constant, the decrease in bank deposits and the corresponding reduction in commercial bank reserves limit the available credit for the economy, increasing eventually the cost of bank credit. As highlighted, replacing bank deposits with CBDCs might introduce instability in commercial bank reserves, creating challenges for both commercial banks and the central bank in managing liquidity. Large, frequent, and unpredictable transfers of deposits into CBDCs could lead to significant volatility in commercial bank reserves held at the central bank. This volatility can impact monetary policy through multiple interrelated channels.

- Central banks must accurately anticipate the flow of funds in and out of the commercial banking system, especially in payment system operations, to achieve monetary policy goals, particularly short-term interest rate targets. High volatility in commercial bank reserves complicates a central bank's ability to predict its balance sheet components, affecting the size and frequency of Open Market Operations.
- Volatility in commercial bank reserves may prompt banks to maintain larger reserves not only for daily payment transactions but also to handle potential withdrawals for CBDC funding, especially in stressful market conditions. This increased need for liquid buffers reduces funds available for long-term lending, weakening the credit channel.
- The accumulation of excess liquidity can disrupt the transmission of policy rate changes to interbank markets, crucial for the effectiveness of Interest Rate regimes. Banks might have to offer higher deposit rates or secure funding from more expensive and unstable sources, leading to elevated lending rates and decreased credit availability to the private sector.

Wholesale CBDC Implications

Alternatively, Wholesale Central Bank Digital Currencies (w-CBDCs) resemble reserves and do not impact monetary policy implementation or transmission through balance sheet adjustments. In-

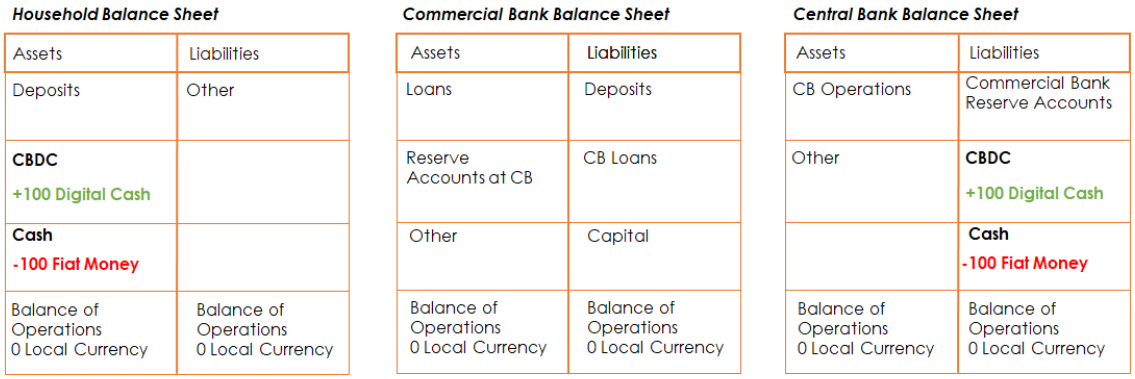


FIGURE 1: How exchanging cash for CBDCs impacts the balance sheet

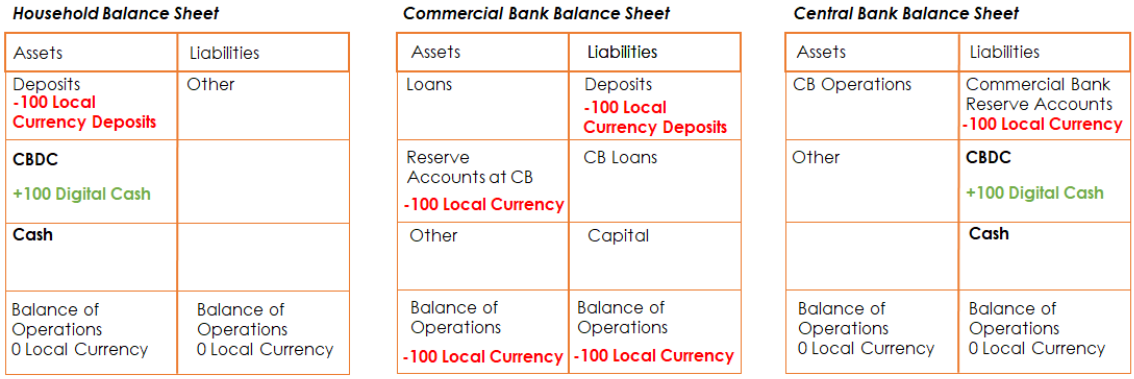


FIGURE 2: How exchanging bank deposits for CBDCs impacts the balance sheet

stead, they influence monetary policy by improving payment system efficiencies and causing shifts in market structure. When a central bank introduces w-CBDCs, financial intermediaries can obtain these currencies in the Real-Time Gross Settlement (RTGS) system by transferring funds from their reserve balances. This issuance of w-CBDCs alters the liability composition of the central bank's balance sheet, increasing w-CBDCs while reducing commercial banks' reserves. The balance sheets of financial intermediaries also reflect similar adjustments in their asset composition. Once issued, w-CBDCs can be transferred between financial intermediaries within the Distributed Ledger Technology (DLT) platform without impacting the central bank's balance sheet, furthermore, Intraday w-CBDCs, issued during the business day and redeemed nightly, do not affect the overall size of the central bank balance sheet. Since w-CBDCs are primarily designed for interbank settlements and other financial transactions among institutions, they do not lead to deposit disintermediation or digital runs.

Cross-Border Use of CBDCs

The introduction of Central Bank Digital Currencies (CBDCs) in international transactions aims to extend the use of central bank money to non-residents. Currently, electronic central bank money is limited to local banks within a country and cannot be utilized for cross-border or offshore transactions. In securities settlement systems, local banks can use central bank money to settle treasury securities purchases, but cross-border and offshore transactions rely on commercial bank money. In foreign exchange transactions, non-resident banks cannot have accounts at the host central bank, and trading parties cannot directly exchange claims using central bank money. Instead, foreign currency transactions involve correspondent banks, leading to a complex network of intermediaries, high costs, lengthy transaction chains, and extended settlement periods. The international use of Central Bank Digital Currencies (CBDCs) poses monetary policy challenges for both the issuing and recipient nations.

- For the Issuing countries, in case of an high foreign demand for their CBDCs, the currency, being held abroad, reduces the issuing country's control over monetary aggregates. This can also result in appreciation pressures on exchange rates, potentially impacting inflation and monetary policy.
- With respect to Recipient countries, the Increased use of foreign CBDCs reduces domestic monetary authorities' control over liquid-

ity. While this substitution is similar to traditional dollarization seen in countries with high inflation and exchange rate volatility, CBDCs' ease of access can accelerate this process. Greater currency substitution negatively impacts seigniorage for the recipient country.

- Considering both Issuing and Recipient countries, faster cross-border settlement can cause rapid flow of liquidity between different currency markets. This speed in cross-border payments can amplify capital flow volatility, affecting domestic monetary authorities' ability to manage exchange rates and monetary policy. Additionally, increased use of wholesale CBDCs for cross-border settlement could lead to higher and possibly more volatile demand for central bank money within the day. Non-resident banks having access to intraday wholesale CBDC might raise demand for overnight reserves held by resident banks, impacting liquidity management, liquidity prices, and, consequently, the transmission of monetary policy.

Architecture of the Digital Euro Environment

Architecture of the Digital Euro Environment

The two-year investigation phase on the Digital Euro guided by the ECB finally concluded on October 2023 and has left as dowry the drawn lines of the possible future Architecture of the Digital Euro Environment which will rely on the division of roles between the Eurosystem and the Private Sector through an Hybrid Distribution Model. The Digital Euro Scheme will tailor the role of supervising the PSP and be in charge of the settlement practices, ensuring that the ECB can constantly monitor the total stock of Digital Euros within the system and its related total liabilities. On the other hand, the supervised intermediaries will manage the onboarding practices, the validation and monitoring of the transactions, and the funding/defunding related activities. Contextually to the investigation phase, the ECB, from July 2022 to February 2023, conducted a prototype exercise with the aim to test the technical possibility of integrating the Digital Euro design choices into the existing European payment environment. The exercise has involved both the ECB, which developed for the exercise purpose a UTXOs-based Settlement Engine named NXT, and a pool of private partners that developed several front-end solutions based on a draft of use cases defined by the ECB

Architecture of the Digital Euro Environment

The actual payment landscape is living all across the globe a moment of intense renewal due to the fast evolution of technologies that permits innovative ways of performing payments. Focusing on the European environment, the latest studies have shown that the evolution of payment services is currently causing a drastic change in the attitudes of Europeans. The use of cash is constantly diminishing in favor of the much more innovative digital payments, in fact, from 2016 to 2022 the number of transactions performed with cash has passed from 79% of the total amount to 59%, while the payments performed with other payments method as cards or mobile app have eroded the cash share showing an increase of the 20% in the same period. It is important to note that mobile app payments passed from a non-significant percentage of the total to 3% of the market. Looking at the total value of money moved by the payment methods the trend showed a similar pattern with the cash that lost 12% of the market share in favor of the other payment methods. In this case, the mobile payments apps have increased since covering 4% of the total value of the transactions.

This scenario is the background where the project Digital Euro was born in October 2021. Since the beginning of the investigation phase, the ECB has not hidden the necessity of the development of a technology that could avoid the decline of central bank money as the center of the exchange system in the Eurozone in favor of the most innovative digital currencies and payment methods.

The Digital Euro is not thought of as a possible substitute for the Euro but as a complementary instrument that will ensure the continuity of the central role of the fiat money even into a much more digitalized payment system. The ECB has clearly stated that the Digital Euro will be a direct liability of the Eurosystem being as the Euro a central bank money. This feature is cardinal in the ECB plan, as it will ensure the maintenance of the European fiat currency as an anchor for the payment system. Using the words of the executive member of the ECB board Fabio Panetta "Our priority for the Digital Euro project has always been clear: to preserve the role of central bank money in retail payments by offering an additional option for paying with public money, including where this is not possible today, for example in e-commerce" [33]. The development of a European CBDC will also improve the autonomy of the Union regarding payment services, indeed, the cards payment services within Europe are in charge of a majority of non-European corporates. Considering so, it is clear that the development of an all-European digital payment environment that will take advantage of the collaboration between the private sector and the European private intermediaries will guarantee the growth of the market share in charge of European corporates. In October 2020 the ECB published the Report on Digital Europe which underlined the core principles and the other possible features of the European CBDC. The first and most important of these states that the Euro and the Digital Euro are two faces of the same coin and so a Digital Euro will always be exchanged at par with its paper counterpart. Other than that, the analysis one more time defines the future state of the fiat currency of the Digital Euro, confirming that it

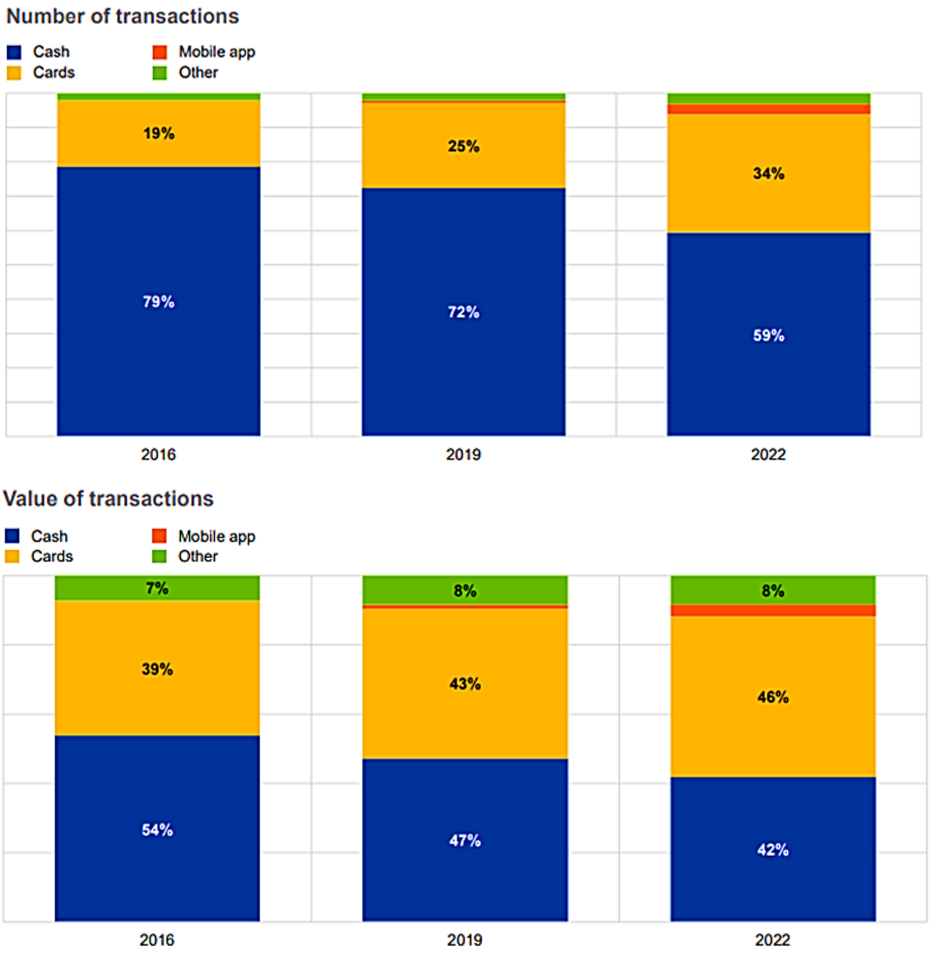


FIGURE 3: Share of payment instruments used at the POS in terms of number and value of transactions, 2016-2022, euro area [18]

will be a direct liability of the Eurosystem, this implies that the trust in the Digital Euro will always be ensured over time by the ECB. The implications related to these first three statements subtend that the total amount of the Digital Euro will always be monitored under the control of the ECB. The other core principles define that the Digital Euro must be accessible at the same condition and without any form of discrimination in all parts of the Union and that innovative solutions designed by the private sector in payment solutions will always be encouraged. The Digital Euro Report also includes some scenario-specific requirements and other characteristics that the ECB has studied during the investigation phase and that regards the capability of the Digital Euro to be integrated into the existing payments infrastructure while also supporting the growth of the European payment services sector, helping its digital innovation, and promoting the reduction of its environmental footprint. Another important goal that the ECB aims to reach with the issue of the Digital Euro is digital inclusion that could be boosted by an instrument that relies on the private sector for its distribution but is not linked with the characteristic boundaries of their financial instruments, such as the requirements for the opening of a bank account.

In the next paragraphs, the focus will be put on the findings related to the investigation phase guided by the ECB and the next steps drawn for the preparatory phase that started in November 2023.

Digital Euro Environment: The Roles of Eurosystem and Private Sector

The role that the Eurosystem will cover within the Digital Euro environment will play a crucial part in the definition of the issuing structure of the European CBDC. In fact, since the beginning of the investigation phase, the ECB has put the lens on the design of what the Digital Euro Environment will look like. Since the second report, the ECB focused on defining which issuing and distribution model will fit the best its goals with the Digital Euro. The main differences regarding the models that are being studied regard the roles of the Eurosystem and its interaction with the Private Sector. Three models have been taken into consideration by the ECB:

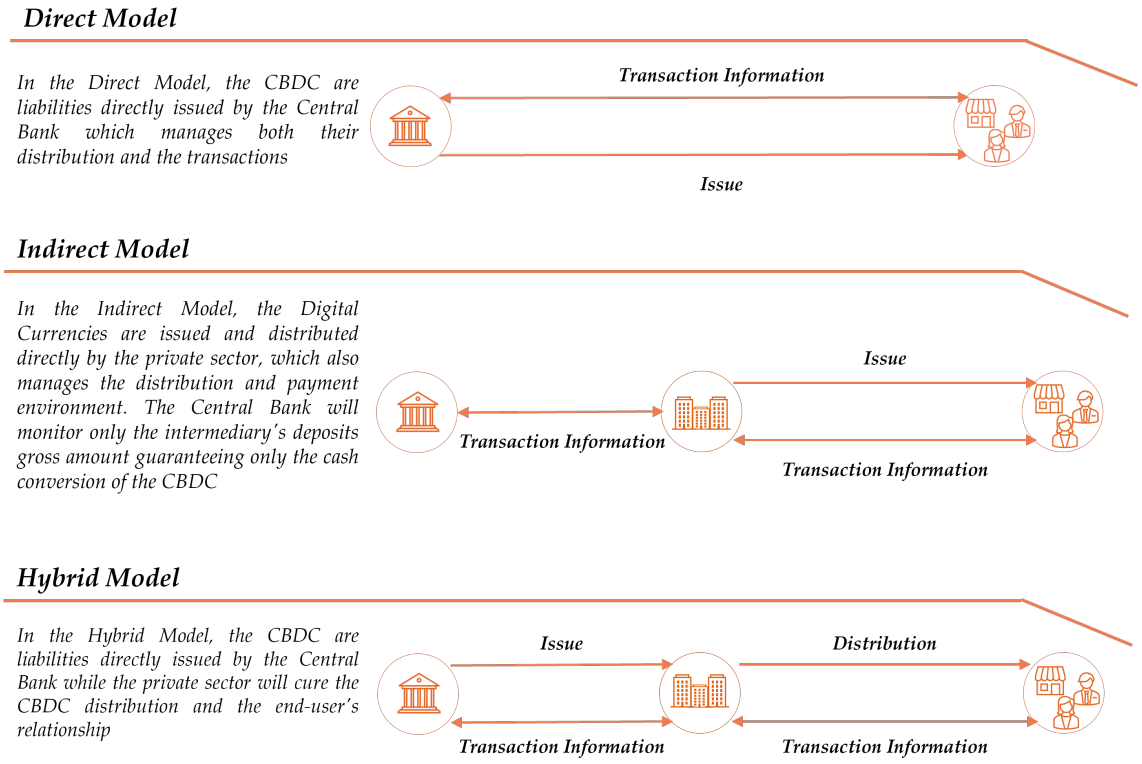


FIGURE 4: CBDC issuing and management models

- Direct Model;
- Indirect Model;
- Hybrid Model.

In the Direct Model, the Digital Currencies are issued and distributed directly by the Central Bank, which, acting as a Bank, will record them as liabilities in its balance sheet, control all the transactions, and monitor all the users' accounting. In the Indirect Model, the Digital Currency environment will be managed, since their issuing to the settlement of the transactions by the private sector. In this configuration, the Central Bank will monitor only the intermediary's deposits gross amount guaranteeing only the cash conversion of the CBDC. The Hybrid Model involves the Central Bank managing the Digital Currency transactions and having the view of the single positions while the private sector will be in charge of the relationship with the users and the payment confirmation system.

Considering that being a fiat currency is one of the main characteristics of the Digital Euro, it is clear that the ECB has opted for a hybrid configuration. From a legal point of view, in June 2023 the European Commission accepted this configuration through the regulative proposal on Digital Euro. First, Article 3 establishes the Digital Euro as the digital form of the single currency, and Article 4 claims that the ECB has the exclusive right to authorize the issuance of the Digital Euro and the national central banks may request to issue it, in accordance with the Treaties. Thus, these institutions would be the direct liability towards the Digital Euro users. Article 4 puts a robust legal basis for the issuance of token and/or account-based CBDCs, legitimizing the Digital Euro. Furthermore, Article 13 specifies the duties of a Payment System Provider for the euro to be utilized as a unified currency throughout the Union. This entails providing funding and defunding functionalities and allowing users of the Digital Euro to automatically defund any excess Digital Euro holdings over any limitations the ECB may adopt (for example, holding limits) to a non-Digital Euro payment account like a business bank account when a Digital Euro payment transaction is received (also known as the "waterfall approach"). This also includes giving users of digital platforms the option to employ the "reverse waterfall approach" and make a Digital Euro payment even when their holdings are insufficient to cover the transaction. In addition, it is stated that Digital Euro users shall only enter a contractual relationship with PSPs and not the European Central Bank or the national central banks. Moreover, it is also important to highlight that the payment service providers shall make available to the public, free of charge, accessible information about the specific features of Digital Euro payment services and the conditions of their distribution. The Digital Euro Environment as it is designed by the ECB, will lay on the equilibrium between the duties of the private sector, represented by the Supervised Intermediaries, and the ones of the Eurosystem. These could be classified into four distinct pillars that represent the milestones of the

Digital Euro Environment:

- User Management;
- Transaction Management;
- Settlement Management;
- Liquidity Management.

The Eurosystem will be in charge of managing the settlement practices and supervising the activities of the intermediaries, while the Supervised Intermediaries will manage the onboarding practices, the validation and monitoring of the transactions, and the funding/defunding related activities. The choice of relying on Supervised Intermediaries as PSP is driven by the advantages that could be taken by the actual cooperation in force for the European payment system. Considering so the supervised intermediaries' experience with the end-users will make them the "best placed to provide user-facing services and to build new business models"[17]. Other than that, as stated by Emilio Barucci[4], we can see this choice in the intent of the ECB to preclude both the big tech firms and teleco companies from entry into the Digital Euro Environment. The Eurosystem will lead the maintenance and management of the back-end infrastructure that will guarantee the settlement of the transactions, ensuring for Digital Euro the status of public goods such as cash. Other than that, thanks to the consideration that emerged from both the investigation phase and the prototype exercise, the ECB has delineated other several related services that will be in charge of the Eurosystem such as the maintenance of an "onboarding register", which are stored the data on the accounts opened at the PSPs, and the management of the alias lookup component that will be "responsible for creating new Digital Euro account numbers (DEANs) and mapping each DEAN to the PSP responsible for servicing the underlying holdings"[9]. Is it clear that, to permit a wide distribution among users, the costs related to the basic subsidiaries' services, such as the opening of a wallet, the defunding activities, and the payment services are not to be charged to the private citizens. The actual designated configuration will follow the current market model in force for the electronic payments, which allows the cost to be charged by the private sector to the merchants. The UE will also prevent overcharging practices that will damage merchants who will be legally obligated to accept the new CBDC as a form of payment. Furthermore, Article 17 of the Digital Euro regulation proposal discusses the fees on Digital Euro payment services, establishing that payment services providers shall not charge fees to natural persons as referred to in Article 13(1), points (a), (b) and (c), for the provision of the basic Digital Euro payment services.

Transaction and User Management

In the Digital Euro Environment, the supervised intermediaries will act as the principal counterparties of the users being also the distribution channel for European CBDC. The activities related to the accounts and wallets opening and management, offering of payment services, onboarding, and offboarding practices, as well as supervisory activities such as Know Your Costumers and Anti Money Laundering checks will be administrated by the supervised intermediaries. Regarding the latter, Directive (EU) 2015/849 of the European Parliament on the prevention of the use of the financial system for the purposes of money laundering or terrorist financing and Regulation (EU) 2015/847 on information accompanying transfers of funds are extended to Digital Euro payment transactions in the legislative proposal. Furthermore, Article 37 defines the Anti-money laundering rules applying to offline Digital Euro payment transactions. It established that transaction data shall not be retained by payment service providers or by the European central banks and the national central banks while funding and defunding data shall be retained by PSP in accordance with the AML regulations. Moreover, article 37 specifies that transaction and holding limits shall consider the need to prevent money laundering and terrorist financing.

As stated by the ECB the onboarding services made available by the private sector will rely on the existing and established procedures that are used to permit the opening of classical payment accounts. According to the latest ECB decisions, if there is a preexisting contractual relationship, the onboarding information used by the intermediaries should be the same that it already owns, while in case of new clients, the intermediaries should apply the KYC checks as already disposed of by the EU legislation framework. The ECB also states that it is forbidden during the Digital Euro onboarding process to force the users to open a non-Digital Euro-related account. The onboarding process will provide the users with a Digital Euro account number (DEAN), which will serve as the account identifier and could be shared in order to receive payments. In case a user changes its PSP the DEAN shall be ported as well as the Digital wallet. The payment services providers will also handle the checks needed to identify if a user has already opened a Digital Euro account with another intermediary. The business users, during the onboarding process, will receive from the intermediary an upgraded POS that shall guarantee the possibility of performing Digital Euro transactions and several DEANs that will deepen on the signed commercial agreements. The offboarding process will follow the processes typically applied in the case of the cessation of a bank account, such as the defunding of Digital Euros in favor of bank accounts or cash. Other than that, the PSP will have to guarantee the transaction management foreseeing the application of procedures that will ensure the authentication of the parties involved in the transaction, its validation, and the other post-settlement procedures. Another

FIGURE 5: Digital Euro Tasks Division

mandatory activity that will be led by the private sector, as in force to manage the wallets monitoring and management activities, will be the reconciliation of the accounts.

For what concerned the legislative framework, different articles address transaction and user managements activities. First, Article 25 imposes that PSP distributing the Digital Euro shall ensure the functionalities of users European Digital Identity Wallets. Furthermore, Article 31 enforces the PSP to enable Digital Euro users at their request to switch their Digital Euro payment accounts to other payment service providers while maintaining the same account identifiers.

The transaction management is further regulated by Article 30 on the settlement of Digital Euro payment transactions, which establishes the differences between online and offline transaction settlements. Moreover, Article 29 requires PSPs to verify every calendar day whether any of their Digital Euro users are listed persons or entities and Article 27 defines the dispute mechanism that sets the rules to dispute a payment by the payer after a successfully completed financial transaction. Finally, Article 28 outlines the front-end services that PSPs distributing the Digital Euro shall provide to Digital Euro users when accessing and using the Digital Euro payment services.

Settlement

The designed model of the architecture of the Digital Euro foresees that the settlement activities must be in charge of the Eurosystem. As noted by Fabio Panetta[31] in his speech on the role of the Eurosystem in the Digital Euro Environment, the choice of making the Eurosystem directly involved as the main actor in the settlement process will ensure full control of the issuance and settlement of the Digital Euro. At a technical level, the settlement activity involves two distinct moments: the first requires verifying the disposal of the funds that must be moved from the payer account and the consequential transfer into the payee account, and the second involves the registration of the transaction into the ledger. Through these activities, the Eurosystem will always be conscious of the total stock of Digital Euros within the system and its related total liabilities.

Liquidity Management

Supervised Intermediaries, according to their role of managing the front-end users relationship, will have the mandate to create, manage, and supervise the users digital wallets that represent the vault where the Digital Euro will be stored. Considering that, is it clear that one of the duties in charge of the private sector will also be the managing of the funding and defunding of users holdings in Digital Euro. In order to facilitate a wide distribution of the Digital Euro it has to be permitted for users to be able to fund directly their wallets with cash or by transferring money from their bank accounts to their wallets and vice versa. The funding/defunding modalities defined for the Digital Euro are designed to accept both online and offline practices. A bank account wont be a prerequisite to have access to digital wallets, but to feed the wallets to an online mechanism it will be possible to link one bank account to it in order to also take advantage of the waterfall/reverse waterfall engines (that will be explained in detail further in the analysis). The online provision of Digital Euro could be performed to any bank account of the user, but it is important to remark that only one could be used to automatically have access to the waterfall mechanism. In the case of offline holdings, the users could only fund and defund their wallets manually and only when their devices are connected

to the internet. On the other hand, will always be possible to feed the Digital Wallet through physical deposit of cash. Technically when a user funds their wallet with a transfer from bank deposits, he is converting commercial money into central bank money. In this process the bank will erase its liability and the ECB will be charged for a new one equal to the amount of funds that the user has converted from commercial money to Digital Euro. With this configuration, the ECB will have only direct interactions with the supervised authorities having the cognition of the wallet amount and the circulating mass of Digital Euro but without knowing anything about the sensitive information about the owners of the wallets that will be only under the private sector jurisdiction. It is important to state that considering that the Digital Euro will be an ECB liability, the wallets will be segregated with respect to the other accounts recorded in the intermediarys balance sheet. This approach will ensure that in case of bankruptcy of an intermediary, the ECB could move the segregated Digital wallets to another intermediary ensuring the protection of the end-users. At the end of the investigation phase, the ECB also noted that the portability of Digital Euro Wallets should be as simple as possible permitting the users to "switch by asking the new intermediary to initiate the porting procedure, similar to how users can take their current mobile number with them when switching to a new provider"[16]. With the scope of harmonizing the user funding/defunding experience, the ECB has also stated that the supervised intermediaries have to ensure a common baseline of functionalities. Not less important the ECB has stated that the Funding/Defunding environment should be available for end users 24/7 and 365 days for year.

Liquidity management is partially regulated by Articles 4 and 13 of the Digital Euro regulation. Article 4 declares that the Digital Euro must be a direct liability of the European Central Bank or of national central banks towards Digital Euro users, while Article 13 extends the framework of Directive 2015/2366 on payment services in the internal market to Digital Euro. Those articles not only define the actors described in Figure 3 but also regulate the liquidity management roles, such as funding/defunding procedures, waterfall and reverse waterfall approaches, and issuance and redemption.

Distribution Model

In the process of identifying the most suitable model to ensure a wide and fair distribution of the Digital Euro, the ECB has sifted several different models, in particular in the first stage of scheme definition the major factors taken into consideration have been the presence of: "Technical rules & standards for interoperability and common acceptance of the different PSPs solutions (e.g. messaging standards, API specifications, Minimum requirements for front-end (e.g. user interface, acceptable form factors) ensuring access for all and inclusion, Common minimum rules for the branding, Security requirements, Certification and compliance, Fraud threshold, End-user protection mechanisms"[19]. The ECB has initially taken into consideration four main models:

- Issuance Model;
- Open Access Model;
- End-to-End Solution;
- Payment Scheme Model.

In the Issuance Model, the Central Bank will be only in charge of the issue of the CDBC while all other aspects, including transaction settlement, will be a private sector affair. The Open Access Model instead requires that the Central Bank will only define the access rule to the market and guarantee the transactions settlement infrastructure. In this configuration, the market will regulate itself with an obvious decrease in the user's experience harmonization. These two models have not been considered the most suitable for the ECB goals, in fact, the intrinsic features of these imply a possible market fragmentation due to intermediaries' free of movement in defining their solutions that will bring a not optimal distribution degree of the Digital Euro. The End-to-End Solution implies that the Central Bank will have to offer an all-around environment for the CBDC, including issuing, settlement, and payment services. This scheme will potentially slow the technological innovation within the CBDC environment reducing the financial inclusion degree under the optimal threshold desired by the Central Bank. The Payment Scheme Model simply requires that the Central Bank defines the common regulatory framework leaving a wide degree of movement to the private sector in developing their solutions in acceptance of the shared environment rules. This model is characterized by a shared harmonized baseline in the user experience without compromising the role of the private sector in developing innovative solutions for the users. The ECB in defining the "Digital Euro Scheme" has opted for this last configuration for the distribution model of the Digital Euro and to determine a shared robust and clear framework has also constituted a task force with the mandate of defining the Digital Euro Rulebook.

The Digital Euro Scheme

The Digital Euro Scheme should define a shared common set of rules, standards, and procedures that will have to be accepted by the supervised intermediaries in order to be authorized to distribute the Digital Euro. The ECB thought promoting the Digital Euro Scheme aims to define a harmonized user experience that will ensure a capillary diffusion of the Digital Euro among all the pan-European areas. This approach will define a common user experience

while guaranteeing a flexible design process in the choices of the private sector that will guarantee innovation in developing the most suitable solutions in order to match the end-user' preferences. The Digital Euro Scheme will ensure the reach of the ECB goals allowing both the central role of the Eurosystem in the issuing and management of the total mass of the Digital Euro and ensuring the necessary degree of freedom that it leaves to the design options taken by the PSP the possibility to aim to the improvement and innovation in the digital solutions that will be delivered to the end users. The ECB Digital Euro Scheme Rule Book points out three levels of services that supervised intermediaries should/have to provide in order to be allowed to the Digital Euro distribution:

- Core Services;
- Optional Services;
- Value added-services.

Core services are the features that the intermediaries will be required to offer to the users, some of them have already been illustrated during the analysis and others will be shown in the following parts, and these include: "

- Opening a Digital Euro account;
- Onboarding and "Know Your Customer";
- Closing a Digital Euro account and offboarding end-users;
- Payment instrument management (provision and maintenance);
- Linking the Digital Euro account to a payment account;
- User life cycle management processes;
- Funding (manual and automated);
- Reverse waterfall;
- Defunding (manual and automated);
- Waterfall transaction initiation (one-off transactions);
- Authentication;
- Payment confirmation/rejection notification;
- Refunds;
- Dispute/exception management"[15].

The optional services, instead, would be not mandatory features that the intermediaries could implement and offer to their users. The Rulebook will define a list, that is still under management, of desired possible optional features such as:

- Portability, or the possibility for the user to transfer Digital Euro access from one intermediary to another one.
- Recurring payments, defined as the feature that guarantees the definition of a schedule of days when a payment should be automatically executed, such as for house rent or electricity bills.
- Pay-per-use enabled via pre-authorization.
- Payment initiation service, or triggering the initiation of a payment from a Digital Euro account held by another intermediary.

The value-added services will be left to the discretion of the private sector. This will provide a degree of freedom that will enhance the solutions offered to the end users. In the third phase of the Digital Euro Investigation, there are reported examples of them such as the DVP (Delivery vs. payment) and the so-called "splitting the bill" functionality. The ECB has also clarified that in its first release, the Digital Euro distribution will be focused on the Euro Area, while access to the European Economic Area and selected third countries will be taken into consideration as the second part of the process.

The Payment System

To make the Digital Euro reliable, the ECB, since the start of the analysis of the distribution model and the payment scheme, has stated that the Digital Euros payments must be available both online and offline to ensure a high level of distribution and fungibility. The possibility of making both online and offline payments will be a key feature in the challenge of making Digital Euro transactions similar to cash transactions. The digital architectures that are under study by the ECB to secure a suited transactions validation mechanism require two distinct solutions for the different types of transaction execution. It is important to state that for the offline transaction, there will be required offline holding amounts that will be subjected to limitations. This limited amount would be a fraction of the total limited amount detained by the users in their wallets. The Digital Euro scheme will provide a third-party validation mechanism for the online transactions, which will also have a near-to-instantaneous settlement provided by the Eurosystem, while the offline transactions will implement a peer-to-peer validation mechanism. The peer-to-peer mechanism requires that the settlement will be made instantaneously on the user's devices while the online accounts will be updated once the connection is restored. Is it clear that the offline transactions will have a privacy profile much more similar to cash than the online ones, for these the ECB has assured that the privacy of the users will be put as the first priority and that they will have the same security profile as the actual electronic payment solutions. Under the privacy profile is it clear that online transactions rely on a so-called account-based user identification model. In these specific models, the users are identified by a unique account which transactions are performed with a minor degree of privacy than the ones performed with cash, on the other hand, the account-based models permit an improvement in terms of AML and CFT controls and guarantee a major degree of control on the Digital Euro mass. The peer-to-peer authentication

model thought for the offline transaction instead, has some features in common with the asymmetric cryptography algorithms[1]. Even if it is not clear the technological feasibility, the ECB has stated that offline transactions that regard exchanges of small amounts of Digital Euro will be guaranteed an even higher level of privacy. Another important feature that has been defined in detail at the end of the investigation phase is the funding waterfall mechanism. The ECB has enlightened the importance of guaranteeing the consistency of the Digital Euro liquidity management provided by the PSP, specifying that the wallets linked directly to a bank account must guarantee solutions that assure payment continuity through the implementation of a waterfall mechanism. The waterfall configuration requires that if the bank account linked wallet does not have enough Digital Euro to complete a payment an automatism will switch immediately the Euro in the bank account of the users in Digital Euro in order to complete it. On the same level, considering the maximum amount limit of detainable Digital Euro on a wallet, an inverse-waterfall mechanism has to be assured by the payment system provider. Practically, if a user, for instance, receives a payment in Digital Euro that will make its bank account linked wallet flood the detention limit, a mechanism should automatically exchange the CBDC into Euro. It is clear that in order to accomplish their scope of ensuring a continuous payment experience for the users, the funding/defunding mechanisms have to run 24/7 and 365 days a year.

As reported at the end of the investigation phase as an optional feature the PSP could include the possibility of performing recurring payments through the service that it provides. The user could instruct the payment through the setting of some defined parameters, for instance, the payment schedule, or in case of uncertain amounts could fix a maximum cap after that the recurring payment is not performed. The ECB, aiming to ensure a homogenous user experience, has also encouraged the supervised intermediaries to provide funding and defunding systems as harmonized as possible. It is important to enlighten that as specified by the ECB, the Digital Euro payments would be guaranteed, at least in the first release, all across the Euro Zone and would be accessible 24/7 and the would be possible to perform person-to-person (P2P) payments, point of sales (POS) payments, E-commerce payments and payments to and from Governments (G2X, X2G). Access to the Digital Euro services will be possible through the integration of the Digital Euro services in the existing tools provided by the private sector, such as online banking apps or payment apps. The integration approach will ensure a harmonized playfield for the users that could easily access the Digital Euro-related services within familiar apps, The ECB will also develop a "Eurosystem App" that will embed only core features. The European app will play a crucial point in the financial integration aimed at the Digital Euro as it will be the Digital Euro-harmonized entry point for the end-users. This dual approach is a clear sign of the will of the ECB to promote a high level of financial inclusion within the Digital Euro environment while still guaranteeing the private sector the freedom necessary to develop innovative services. Another clear signal of the ECBs will to promote the integration of the existing technology solutions and financial inclusion even in the Digital Euro environment is given by the consideration of the operative way in which the end-users will perform the payment within stores, e-commerce, and other users. Currently, the ECB has preferred the prioritization of the usage of QR codes, contactless technologies, and Digital Euro accounts (DEAN) in the enlightened payment areas. This approach looks to minimize the dependence on particular device constructors in order to incentivize the Digital Euro environment's financial inclusion. Following the G20 endorsement regarding the enhancement that CBDC could bring into cross currencies payments, the ECB has stated that, after a successful release of the Digital Euro within the Euro Area, will start to study and support the technical feasibility of developing cross-currency functionalities where mutual interest with other jurisdictions are met. Currently, the most realistic approach relies on the interlinked model[2], in which the CBDC systems are linked to each other through contractual agreements and technical links that permit the ease of the sharing of data and communications, the provision of currencies, and the settlement of transactions. Cross-currency payments are also discussed in the Digital Euro proposal with Article 21, where it is established that the ECB promotes interoperable payments between the Digital Euro and other currencies.

Detention Limits

One of the decisions taken by the ECB after the conclusion of the investigation phase regards the possible limitation on the holding of Digital Euro. The Digital Euro amounts held by private citizens in their accounts would be subjected to limitations. The boundary of the detainable amount will be probably defined at the end of the preparatory phase and just before the issuing of the CBDC. For business users, merchants, and governments will be set a zero holding limit, which implies their impossibility of detaining Digital Euro amounts stored in their accounts. The zero holding limit will be implemented through a waterfall engine that will transfer any payment received with Digital Euro directly to the cash account of the entity, contextually a reverse waterfall engine will fund the payments that the entity will make

[1] Consists of the use of a public key to encrypt a message that can only be read by using a private key, and hash function, which consists of mathematical functions that map the input data into a fixed-size string of known hashes

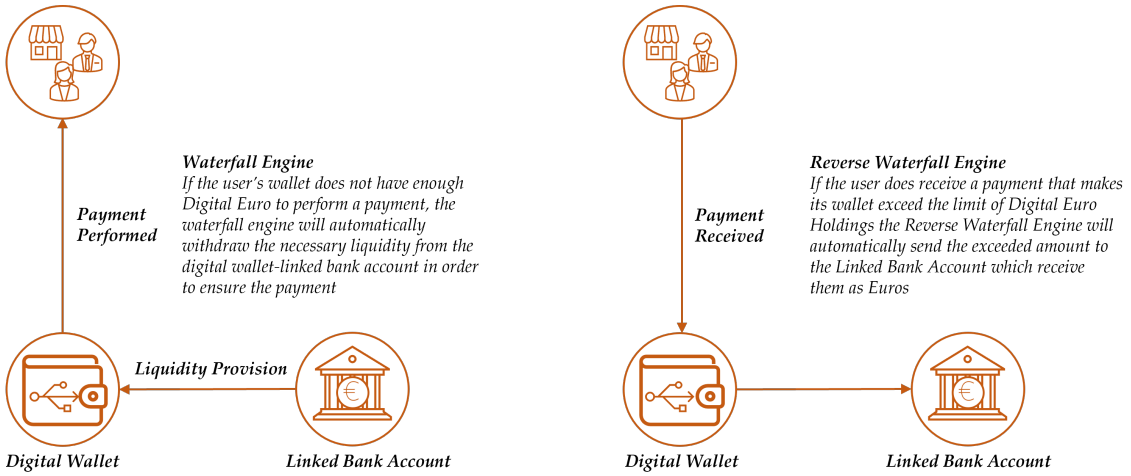


FIGURE 6: Waterfall and Reverse Waterfall Engines

with Digital Euro directly from its ban.

Release Approach

Even if the works on the development of the Digital Euro are not close to being done, the ECB has started to consider, during its investigation phase and in the ongoing preparatory phase the eventual release approach for its CBDC. In the final update about the investigation phase is stated that a two-phase roll-out strategy could be implemented. The motivations behind this decision are principally related to the careful handling that the introduction of a high-innovation level payment system, such as a CBDC, is introduced in an existing environment. A multi-phase release could mitigate the potential issues and risks making possible a gradual resolution of potential crucial problems and also smoothing the process of user familiarization with the instrument. The hypothesized roll-out approach requires a first release that will provide peer-to-peer and e-commerce payments. This choice is driven first by the feedback and studies reported in the "Study on Digital Wallet Features" which has enlightened that users highly value the possibility of performing P2P payment, and secondly on the possibility of creating network effects for the diffusion of the Digital Euro thanks to the possibility given by the P2P payments and for the higher importance that e-commerce is gaining in the European economic environment. The second release instead will ensure the point-on-sale payments. The release of this feature will inevitably face a higher degree of complexity respecting the first phase as it will be required to act in the substitution of the existing payment device infrastructures. In fact, the introduction of the Digital Euro will require adjustments, for instance, in the in-store payment solutions that merchants make available to end users in order to accept Digital Euro Payments.

Prototype Exercise

With the aim of evaluating the feasibility of the features that emerged during the investigation phase, the ECB from July 2022 to February 2023 conducted a prototype exercise that tested the technical possibility of integrating the Digital Euro design choices into the existing European payment environment. The exercise has covered both online and offline transactions and has involved the development of a back-end structure and front-end prototypes. The development of the back-end architecture was in charge of the ECB which also received the support of the Central Banks of Belgium, Germany, Spain, France, Italy, Austria, Portugal, and Finland. Instead on the front-end architecture side, the ECB has benefited from the support of five private sector actors that have shown interest in the analysis, these are CaixaBank, Wordline, EPI, Nexi, and Amazon. Each one of these private actors has developed a specific front-end solution for a particular use cases pool defined by the ECB. The division is reported as follows:

- CaixaBank for Person-to-person online payments;
- Wordline for Person-to-person offline payments;
- EPI for Point-of-sale payments initiated by the payer;
- Nexi for Point-of-sale payments initiated by the payee;
- Amazon for E-commerce payments.

The use cases represent the possible usage of the Digital Euro that the ECB considers the most important to ease the spread of the CBDC among users. It is important to state that during the prototype phase, no personal data were used within the exercise, and the architectural decisions taken and proposed were not mandatory, this implies that the developed solutions for the front-end prototypes will be discharged

while for the back-end it is possible that some components will be used in future. The prototype architecture could be dissected into three main components:

- Core Settlement Engine;
- Wallet Service;
- User Facing apps/devices.

The Core Settlement Engine, as stated before, will be developed directly by the ECB and will oversee the management and processing of the transactions settlement. The Wallet Service, developed by the private partners involved in the exercise, will cover a set of main features that will comprise the client services (managing user wallets/accounts, receiving payment instructions from user-facing applications, converting payment instructions into transaction messages which can be sent to the core settlement engine for settlement) and the client communication service that will guarantee routing payment instructions (and notifications) between different wallet/account management services. The user-facing apps are applications or devices that will be used by the end-users to interact within the system and perform transactions.

The ECB developed for this prototype exercise the back-end settlement solution for online transactions called NXT. The design decision has opted for a non-DLT architecture for NXT that instead relies on the Unspent Transaction Unit (UTXO) Data Model. Architecturally spoken NXT takes advantage of "an open-source messaging technology, serves both as the inter-service communication platform and as a multi-site sharded data store for transactions and UTXOs"[11] named Kafka and is based on two different datasets that store respectively the transactions and the UTXO data. The NXT engine relies on four main layers/actors:

- Validator;
- Coordinator;
- Token Manager;
- Notifier.

The Validator has the goal of effectively checking the inputs that the API sent to the Settlement by controlling the correctness of message syntax and semantics while also checking the cryptographic signatures and the permits regarding the eligibility of the money sender. The Coordinator and the Token Manager are in charge of the UTXO management through the coordination and validation of the transactions within the system. The Coordinator stores the transaction information while the Token Manager is in charge of storing the UTXO data. The data communication between these layers permits the creation of UTXO based on the Transactions data guaranteeing avoidance of transaction duplications and ensuring their validity checks. The Notifier, according to the information received by the Coordinator and the Token Manager, prepares the final settlement of the operations and sends it to the API interfaces for the notification of the results to the parties involved in it. The entire back-end system has proven, as defined in the desired requirement that emerged from the investigation phase, the capability of running 24/7.

With the goal of ensuring the consistency of the prototype exercise and in order to define the desirable deliverables, the ECB has provided to the private sector participants a set of guidelines that described the essential features that had to be developed to reach a successful result from the exercise. This "Technical Onboarding Package" has been released to the public with the scope of preventing the prototype participants from gathering an advantageous market position with respect to future private Digital Euro distributors.

As reported before, the front-end solutions require the development of at least the core functions of the Wallet Services. The Client, which comprises the features related to the custodian wallet management and user and transaction validation, uses an API to directly communicate with the core settlement engine developed for the back-end and provides payment functionality that could be used by the users through the developers API. In particular, the Wallet Services are composed by:

- Custodian Wallet Management;
- Transaction Message Creation;
- User Authentication and Transaction Authorization;
- Connectivity and lookup services among intermediaries.

The Custodian Wallet Management model defined in the guidelines implies that the Client will store the unique user key information that is involved in the authentication and validation of the transactions. As has already been described, even the prototype engine, according to the Digital Euro distribution model, will ensure that the sensitive data such as the validation keys and the related user information wont be shared with the back-end engine. The Client will also be in charge of all the computational algorithms that create and send the transaction message, codified as required by the back-end protocol, to the settlement engine. The guidelines state that in the case of communication between intermediaries, the front-end engines should be able to develop a tool to integrate the sharing of transaction information and validation between the parties. Another innovative feature developed within the front-end prototypes regards the capability of transaction risk profile assessment that will automatically engage due diligence checks. The risk profile will be determined to be one or the combination of the transaction amount and cumulative wallet transaction amounts performed within a predefined temporal window.

The prototype partners developed five prototypes according to the division of the use case reported above. As reported on the Digital Euro Prototype summary and lessons learned the solutions have exploited all the payment technologies assessed in the Digital Euro Scheme (e.g. QR Code, NFT) and have delivered a wide range of solutions that also included mobile payment applications and online interfaces.

Contextually to the prototyping of the online solutions, the ECB has comprised in the prototype exercise perimeter also the request of developing an offline payment solution, and as stated before the partner that was in force to define it was Worldline. The architectural principles defined in the onboarding package guidelines require the development of an end-to-end solution that has to be capable of testing a multitude of consequently executed offline transactions where the validation of these ones had to be in charge of a peer-to-peer validation mechanism. The requirement for this last use case was also that the funding and defunding features had to be tested. The delivered solution is based on "a secure JavaCard applet running in smartphones Secure Elements, and a mobile phone application running as the end-user interface leveraging the secure applet and using near-field communication antennas for data exchange between offline devices"[12] which guarantees all the features described by the ECB including the capability of funding and defunding from the offline application to the online solutions.

Overall, the prototype has shown that an integrated Digital Euro within the actual payment European system is much more than possible covering a wide plethora of services but leaving open the participants to bring innovative solutions to the playfield. In particular, the backend architecture design by the ECB has returned some important hints showing that UTXOs model could be a reliable solution for the settlement environment thanks to its capability to guarantee at the same time a high level of privacy security, linear transactions scalability related to the computational power and the capability of supporting efficiently an issuance and redemption model. Furthermore, the UTXOs embed witness type has shown the possibility of guaranteeing the implementation of more than the transaction types used within the exercise (payment, funding/defunding, and reservation/unreservation of funds). On the other hand, the NXT system has exposed oneself to some potential issues related to high latency in situations with a very large number of transactions. The whole frontend solutions have been able to directly integrate their functionalities with the backend engine, showing that the private sector could support the smooth integration of the Digital Euro in the actual European payment system. It is important to report that all the solutions have been specifically developed for the exercise, so it was not investigated the feasibility of directly integrating the backend engine within the actual market-offered solutions of the partners. An important insight is given by the exercise that some features like cross-intermediaries communications, alias lookup and identify verification services will benefit most if developed centrally and then shared with all the market participants. Another important result regards the offline solution that has shown that even if based on different technologies the architecture of the offline and the online engines could be integrated as well. Obviously one of the main challenges that remains on this front regards the technical limitations for NFT given by the constraints that the fragmentation on the solutions adopted by the smartphone constructors.

Future Architectural Decisions

On the 18th of October 2023 the ECB, after 2 years, declared concluded the investigation phase on the Digital Euro, and from the 1st of November 2023 began the two-year preparatory phase which will survey the market to define the possible providers and partners that will be involved in the architectural development. In this final phase are also going to be tested the features and the business processes that should be ensured by the new Digital Euro Environment. Despite that, some open points still have to be assessed to have a clear view of the future Digital Euro environment. First, the European Commission, on the 28th of June 2023, presented a regulatory proposal that aims to ensure the legal tender for the Digital Euro. It is clear that having a legal tender CBDC would ensure the possibility of its wide acceptance within the Union. The acceptance of the proposal will play a crucial role in the development of the Digital Euro project ensuring its distribution as stated by Fabio Panetta "The proposal is key to ensuring that the Digital Euro brings value to the people, taking the appreciated features of cash into the digital sphere"[20]. Other than that, while the end of the investigation phase has clarified some open points defining that in order to ensure the financial stability of the Eurosystem and to avoid bank disintermediation effects, as reported before, there will be a limit to Digital Euro holdings detained by private users, that will be disclosed in the phase just before the issuing of the Digital Euro, and a zero holdings limit to the business users. Furthermore, to avoid the risk of a Digital Euro used as an investment instrument and to make it as much more comparable to cash as possible the ECB has defined that a remuneration system for the Digital Euro holdings wont be implemented. However, the ECB has not already raised the curtain on the technology underlying the back-end settlement system that will be developed. The possibilities that are taken into consideration regard the implementation of DLT, the reliance on traditional technologies, or a combination of both. The sure thing is that the ECB will carefully take into consideration the security level of the technology and the feasibility of integrating it with the existing end-

user's services.

Foreign Solutions

This paragraph wants to briefly introduce the actual solutions thought by the USA and China for the issuing of their CBDC. It is important to state that the Chinese e-CNY is already at an advanced stage with several tests already concluded while the FED is still evaluating the potential benefits of issuing a digital dollar.

The Peoples Bank of China Architecture for E-CNY

The CBDC Chinese project started much before the ECB program with the 2014 foundations of the Chinese Digital Currency Institute. In fact, the People's Bank of China starting in 2020 has launched several pilot programs that are been conducted in a lot of cities such as Shenzhen, Suzhou, Chengdu, Xiongan, Shanghai, Hainan, Changsha, Xian, Qingdao, and Dalian and where the features designed of the Digital Renminbi are being tested. In the e-CNY architectural model, as the one studied for the Digital Euro, the PBoC supervises all the settlement and clearing activities regarding the transactions performed with Digital Renminbi, the e-CNY will be legal tender money, implying that the private entities inside China must accept it as a form of payment, and the Digital Renminbi also wont bear any kind of interest. The settlement engine relies on a permissioned DLT structure where the PBoC is the only transaction validator within the system, that guarantees control over the transaction operations such as money exchange, transaction deletes, or reverts. On the other hand, the distribution of the e-CNY follows a "two-tier" model where the PBoC is in charge of the issuance of e-CNY to the selected intermediaries (commercial banks, Alipay, Tencent) that must hold the total amount of e-CNY reserves at the PBoC, these are responsible for the digital wallet issuance of to the end-users and of the management of digital wallets. The Digital Renminbi Environment defines also different types of wallets with different daily limits in terms of transaction values and total balance, these limits depend on the amount of personal information users share with the intermediaries, for instance, is it possible to open an anonymous wallet with the highest level of constraints to transactions and account balance. The wallets do not require to be anchored to a bank account and the online transactions could occur between two wallets with the PBoC that operates as a transaction validator. The peer-to-peer offline transactions are permitted but are still not disclosed the technical features that will be underlying the process of data transmission to the Central Authority.

Possible Architecture Design for The Digital Dollar

Despite China and the Eurozone, the USA has not activated a pilot program or an intensive and advanced investigation phase that defines the technical structure of a CBDC. In the United States environment, the public debate around the possibility of issuing a Digital Dollar is still leading to uncertainty with contrasting views among the FED members and the Withe House Staff. However, following the footprints in the speeches and in the official documents is possible to decline some key features that, in case it will ever exist, the Digital Dollar could have. Considering that for the FED Act, the Central Bank did not the permission to create accounts for individuals, the Digital Dollar must rely on the support of the Private Sector which has to manage the issuance and maintenance of the digital wallets and of the development of the payment services. The ongoing considerations do not state if only commercial banks would be allowed to offer Digital Dollar services or if it will be extended to other financial intermediaries, but the FED has recommended the importance of the integration of the CBDC services into the existing financial services. The Digital Dollar, as for Digital Euro and e-CNY, will be a legal tender currency issued at par with the dollar and will be considered as a FED liability. Another important characteristic that would be addressed in future analysis regards Digital transferability which is stated that in the case of an American CBDC, will ensure the transferability between different intermediaries within a harmonized system. Concluding in the "Money and Payments: The U.S. Dollar in the Age of Digital Transformation" the FED has remarked on the importance of a CBDC to be fully embedded into the existing AML and CFT American rules.

Legal Framework

In the previous sections, some architectural designs were discussed, such as the BCE Digital Euro one and the other foreign solutions. However, the technical details are not enough to spread the diffusion of CBDCs. Indeed, it is also important to define the legislative framework, which establishes the whole ruling system behind these digital currencies. Alongside the previously discussed European proposal for a regulation on the Digital Euro, the next paragraphs will address more general legal challenges, which are currently been discussed internationally.

Challenging Aspects of International Monetary Law

First, is necessary to analyze the challenging aspects of the Digital Euro legislation with respect to the rules of international monetary law. We will first discuss the legal characteristics of the currency, and

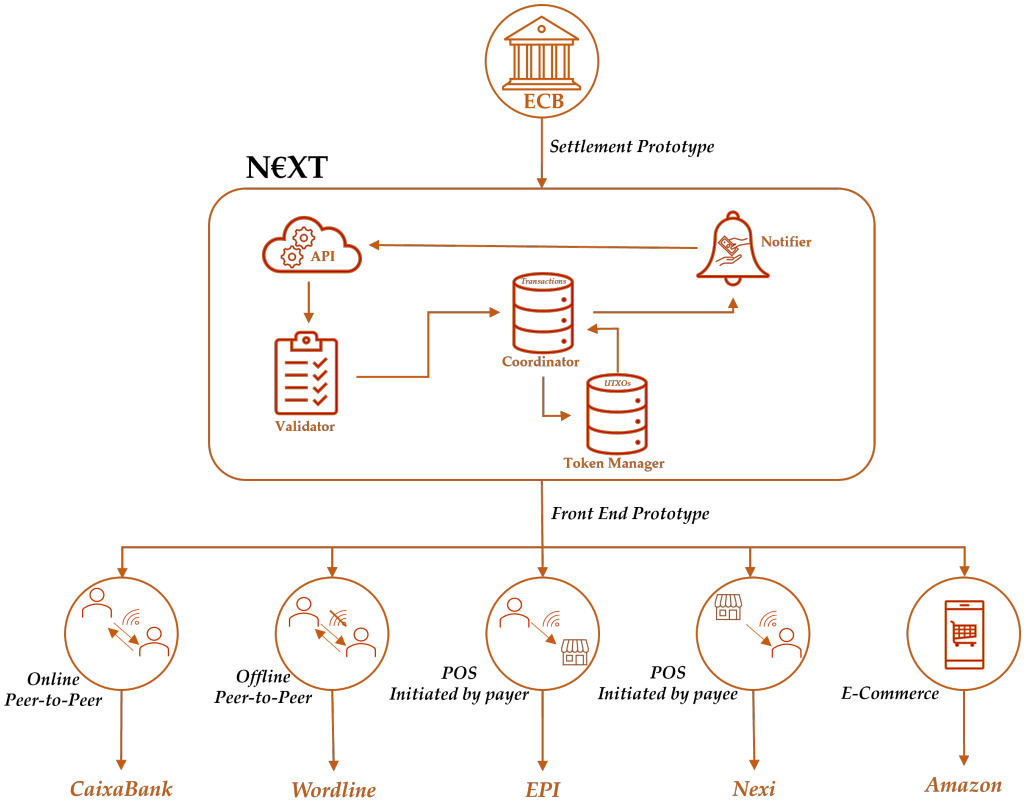


FIGURE 7: Prototype Exercise Scheme

then compare them to the Digital Euro and the legislative proposals of the European Parliament and the Council. As reported in the International Monetary Fund's Working Paper on the Legal Aspects of Central Bank Currency, the basic principle of monetary law provides that it is for a sovereign State to determine and establish its own currency system. The issuance and circulation of currency is a core element of sovereign power. Therefore, many Constitutions contain general provisions on this power, which is subsequently detailed in primary legislation, such as central bank laws. Building upon those international and constitutional law principles, monetary law basically seeks to regulate two issues:

- What is the official monetary unit of the country/monetary union and how is its value determined or defined?
- What are the official means of payment of the country/monetary union?

All States/monetary unions define in legislation both the official monetary unit and official means of payment valid on their territory. Monetary law also establishes which means of payment are officially sanctioned as such by the State/monetary union. Almost all States/monetary unions legally and officially sanction one or more types of means of payment. The main types of official means of payment are banknotes and coins. The State has sanctioned the use of currency essentially through five important legal mechanisms: (i) the monopoly of issuance by the State or its agent, (ii) cours force, (iii) legal tender status, (iv) privileges under private law, and (v) protection under criminal law. Nowadays, in almost all countries, the official means of payment are issued by the State, and in particular its agentthe central bank. For the few jurisdictions where that is not the case, the issuance of "currency" must at least be sanctioned by the State. The second mechanism through which States sanction a means of payment is through cours force. The contemporary meaning of this concept is that the value of a banknote is the amount of official monetary unit printed upon it by the issuer. Banknotes are to be accepted in payment for that value, without convertibility into gold coins. It is this feature that leads economists to call banknotes "fiat money". The third legal mechanism consists of granting by law the power to a currency to extinguish monetary obligations validly and definitively: this power is called "legal tender status". By tendering a means of payment with legal tender status to the creditor, the debtor of a monetary obligation validly discharges his/her obligation. It is prevailing practice that a State/monetary union designates by legislation the means of payment it has issuedits banknotes and coinsas legal tender. Legal tender status is merely one of the means of sanctioning, but not an essential feature, of official means of payment. Hence, the link between the official status of a means of payment and legal tender status is not absolute. In respect of the possible legal tender status of CBDC, the following question arises:

is the sovereigns power to attribute by legislation legal tender status to a means of payment unlimited? The answer is open to discussion, but it is fair to say that the State can only meaningfully attribute legal tender status to a means of payment when that instrument is easily receivable by most of the population. Attributing legal tender status to a means of payment that cannot be received by most of the population might be legally possible but raises fundamental questions, including from a fairness perspective. This is recognized by countries that have attributed legal tender status to means of payment that are not currency: the designated group of creditors that are obligated to accept payment in the said means of payment must also take steps to ensure that payment can effectively be received. The fourth legal mechanism through which States have officially sanctioned payment instruments is by granting them privileges under private law with a view favoring the circulation of "currency" relative to other possible means of payment. However, the currency is not the only means of payment that benefits from private law privileges: the check and bill of exchange, the original payment instruments, also enjoy certain privileges as "negotiable instruments". The State has protected officially sanctioned means of payment by imposing criminal law sanctions on those who counterfeit, damage, or destroy those instruments. So far, national as well as public international law focuses on the suppression of counterfeit or altered banknotes and coins. With respect to CBDC, the fundamental questions that arise under monetary law are:

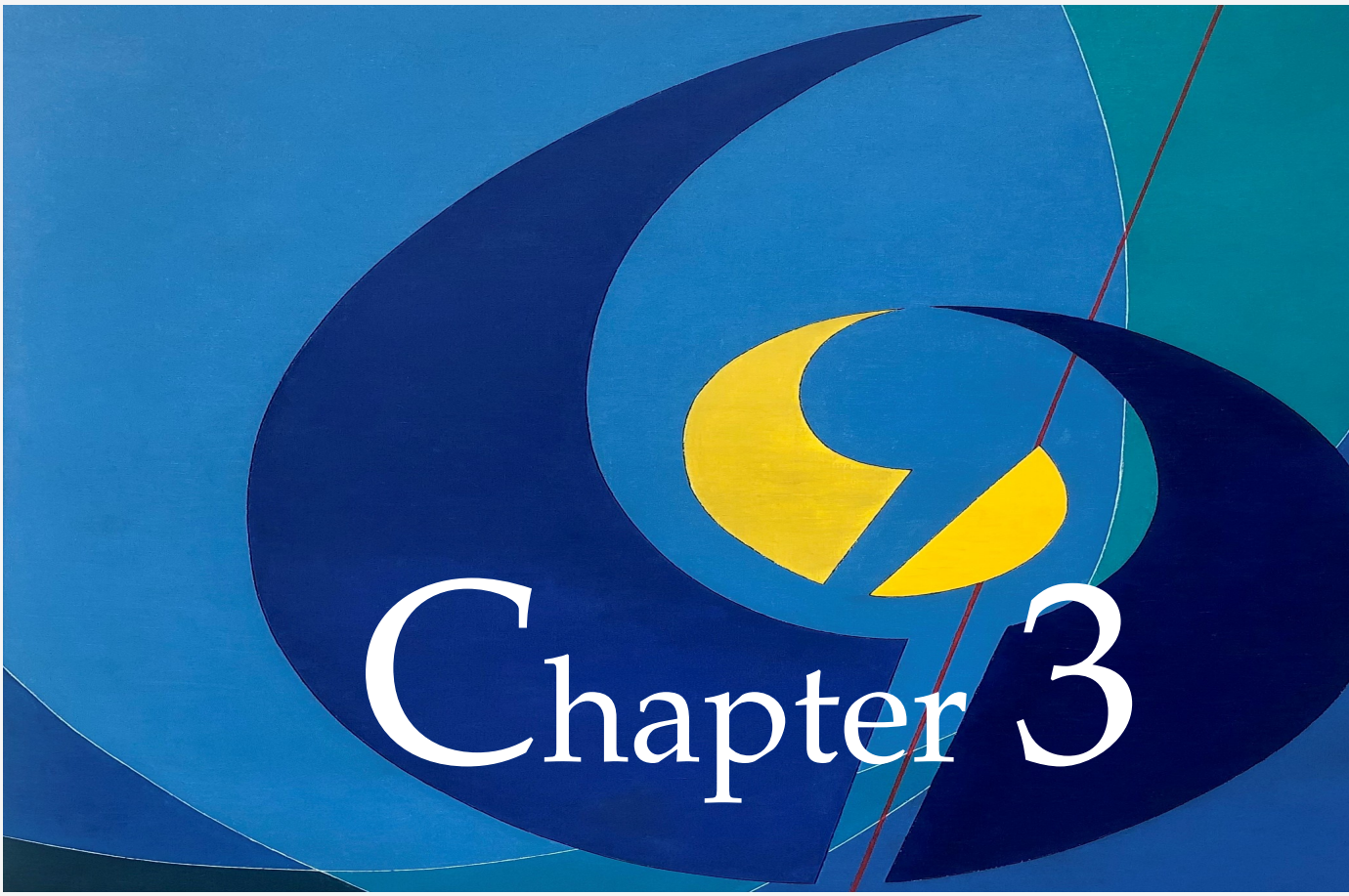
- Is CBDC a new official monetary unit and/or a new official means of payment?
- In function of the response, what are CBDCs essential monetary law attributes?

As discussed above, all states/monetary unions define in their legislation both the official monetary unit and the official means of payment valid on their territory. In this regard, the European Parliament and the Council have drawn up a proposal for a regulation on the establishment of the Digital Euro based on Article 133 TFEU. In accordance with the treaties, the European Central Bank has the exclusive right to authorize the issuance of the Digital Euro, and the European Central Bank and the national central banks may issue the Digital Euro. Within the framework of this Regulation, the Digital Euro does not generate interest. Therefore, the issuance and circulation of currency is a core element of sovereign power, and each Constitution contains general provisions on this power, which is subsequently detailed in primary legislation, such as central bank laws. In principle, the introduction of CBDC would change nothing regarding a State/monetary unions establishment of its official monetary unit. CBDC raises important questions under central bank and monetary law. The legal treatment under those bodies of law will considerably depend on the design features of CBDC.

Legal Tender Digital Euro

Following what has been raised in the previous section, in June 2023 the European Commission proposed a regulation on the legal tender of euro banknotes and coins, where the Digital Euros legal tender is discussed. The focal point of this will be the attribution of legal tender status. In an Expanding Digital age, the growth of electronic payments has led to a general decline in cash payments and the reduction of automated teller machine (ATM) networks in several Member States means there are risks in accessing cash. Thus, the issue of the scope and meaning of the legal tender status of cash has become more prominent in the EU policy agenda, as outlined in the Commissions Retail Payments Strategy and in view of the recent ruling of the Court of Justice of the European Union on the matter. This ruling is significant because it sets out in the Courts jurisprudence the key aspects of the concept of legal tender, which until now have only been found in the Commission Recommendation of 22 March 2010 on the scope and effects of the legal tender of euro banknotes and coins. Although EU law directly attributes the status of legal tender to euro banknotes and coins, neither primary nor secondary EU law defines the concept of legal tender. In its judgment in the legal tender cases, the Court of Justice held that the concept of legal tender of euro banknotes enshrined in Article 128(1) TFEU is a concept of Union law that must be given an autonomous and uniform interpretation throughout the European Union. The concept of legal tender as interpreted by the Court of Justice for euro banknotes implies: (i) mandatory acceptance, (ii) at full face value, and (iii) with the effect of discharging payment obligations, as set out by Point 1 of the 2010 Commission Recommendation. The European proposal is consistent with this Recommendation which outlined a common definition of the concept of legal tender. Furthermore, in order to ensure coherence between the two forms of central bank money (Digital Euro and euro cash), the Digital Euro will also be regulated in a consistent manner with the legal tender of cash, without prejudice to the differences between these forms of the euro. That is why the Commission is making a legislative proposal to ensure the acceptance and availability of cash. The proposal sets out, for the first time in secondary legislation, a definition and regulation of legal tender for cash. There are two main aspects to the legal tender of cash: the acceptance of, and the access to cash. In the absence of EU-level action, the extent to which cash is accepted by enterprises and the ability of citizens and enterprises to get sufficient access to cash will remain suboptimal and variable across the euro area, due to the lack of a common application and interpretation of the concept of legal tender. Article 4 of the proposal defines the legal ten-

der of cash as entailing mandatory acceptance, at full face value, with the power to discharge from a payment obligation. A payee shall not refuse euro cash tendered in payment unless the parties have agreed on a different means of payment or an exception applies. Article 5 sets out the conditions under which a refusal to accept euro cash would be legally possible; such a refusal must be made in good faith, be based on legitimate grounds, and be in line with the principle of proportionality in view of the concrete circumstances in which a payment is to be made. The burden of proof that these conditions are met for such good faith circumstantial exceptions is on the payee. Article 5 sets out two legitimate grounds on which euro cash may be refused on that basis in a non-exhaustive list, namely the tendering of banknotes the value of which is manifestly disproportionate to the value of the amount to be settled, and in exceptional cases where, at the relevant time, the enterprise has no change available or if the enterprise would not have enough change available as a result of that payment to carry out its normal transactions. In order to ensure the acceptance of cash in accordance with Article 4, Member States shall monitor the acceptance of payments in cash and the level of ex-ante unilateral exclusions of payments in cash throughout their territory, in all their different regions, including urban and non-urban areas, on the basis of the common indicators adopted by the Commission and shall assess the situation. Member States shall lay down the rules on penalties applicable to infringements of the Regulation and shall take all measures necessary to ensure that they are implemented. The penalties provided shall be effective, proportionate, and dissuasive. Member States shall, within one year after the entry into force of this Regulation, notify the Commission of those rules and of those measures and shall notify it, without delay, of any subsequent amendment affecting them. Regarding access to cash, Article 8 defines that Member States shall ensure sufficient and effective access to cash throughout their territory, in all their different regions, including urban and non-urban areas. In order to guarantee sufficient and effective access to cash, if a Member is not ensured, it shall set out the remedial measures it commits to take in accordance with Article 9. As regards the interaction between euro banknotes and coins and the Digital Euro, according to Article 15 of the proposal for a regulation on the legal tender of the euro, euro banknotes, and coins and the Digital Euro are convertible into each other at par. This proposal complements the proposal for a Regulation establishing the Digital Euro, as the Digital Euro should complement cash, not replace it.



Commercial Banks in the Digital Euro Landscape

Commercial Banks in the Digital Euro Landscape

European Central Bank has stated that Commercial Banks will play a crucial role in the distribution of the Digital Euro. An hybrid distribution scheme is most likely to be adopted for the European CBDC which entitles Commercial Banks of Digital Euro's conversion, Know Your Customers procedures and retail payments handling. Yet the opportunity for consumers to instantaneously convert euros into CBDC exposes banks to a potential outflow of deposits whose magnitude is directly linked to the grade of adoption of the Digital Euro. The loss of deposits impacts banks' balance sheets and poses new challenges in terms of liquidity and risk management. Furthermore Commercial Banks are required to cooperate with the public sector and other Payment Services Providers in order to allow a smooth integration of the Digital Euro within the payment ecosystem through an efficient infrastructure. This includes the development of user-friendly Digital Euro wallets and their incorporation into existing online-banking interfaces.

The Role of Commercial Banks in the Hybrid Distribution Model for Digital Euro

A key point related to the introduction of the digital euro will be the impact it will have on the financial system, especially concerning commercial banks whose role is yet to be fully defined. In the communications from the European Central Bank (ECB), there is a desire to reassure the banking system by defining the digital euro as a new opportunity rather than a threat. The ultimate goal of the European Central Bank's CBDC (Central Bank Digital Currency) project is to create a secure payment tool, calibrated to ensure the balance of the financial system while accommodating the wave of innovation in the payment sector. The birth of the digital euro is partly linked to the significant evolution happening in the world of payment systems driven by big tech companies. This initiative aims to serve as a defense against the possibility that private companies increase their influence in the market to the point of achieving a monopoly in the digital payment sector.

In this regard, the protection offered by the fact that the CBDC euro falls under the regulatory framework of the European Union ensures particular attention to the impact that its introduction could have on the major stakeholders.

Specifically, it is reiterated that the distribution of Digital Euros will be entrusted to banks and payment systems (PSPs), allowing them to maintain existing customer relationships. In fact, the model identified by the European authorities responsible for the development of the digital currency suggests that commercial banks will be the primary actors in its distribution, converting it from deposits.

As it appears from publications by the commercial banks themselves and sector associations (such as the European Savings and Retail Banking Group), this solution has raised concerns regarding potential risks to the current structure of banking activity. Specifically, there is a liquidity risk that could result in a possible outflow of deposits. This not only reduces the availability of banking institutions but also has an impact on the overall economy. Commercial banks would see a negative effect on their profitability, as they would be forced to reduce their volume of activity, losing the interest margin they would have earned on those deposits. Alternatively, they might need to explore alternative, more expensive, and volatile sources of funding. This could lead to a reduction in access to mortgage financing, consumer loans, and financing for small and medium-sized businesses, both due to a reduction in resources available for lending and an increase in financing costs.

The impact on the balance sheet of the outflow of deposits is expected to affect liquidity management, with a particular focus on the two main indices involved, namely the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio, which will decrease as the quantity of digital euros that can be held per customer increases. Simultaneously, there is the specter of potential bank runs linked to the ability to convert bank deposits (commercial money) into central bank money (ECB money) in a matter of seconds, potentially destabilizing the whole banking system. This aspect will be further explored in section 3.2.

Although the CBDC is seen as posing some challenges for financial intermediation, there are multiple opportunities to be gained from its introduction and widespread adoption. In particular, two main areas have been highlighted where the Digital Euro would provide immediate benefits: monetary and currency policy, as the introduction of the CBDC preserves the anchoring function of the central bank's

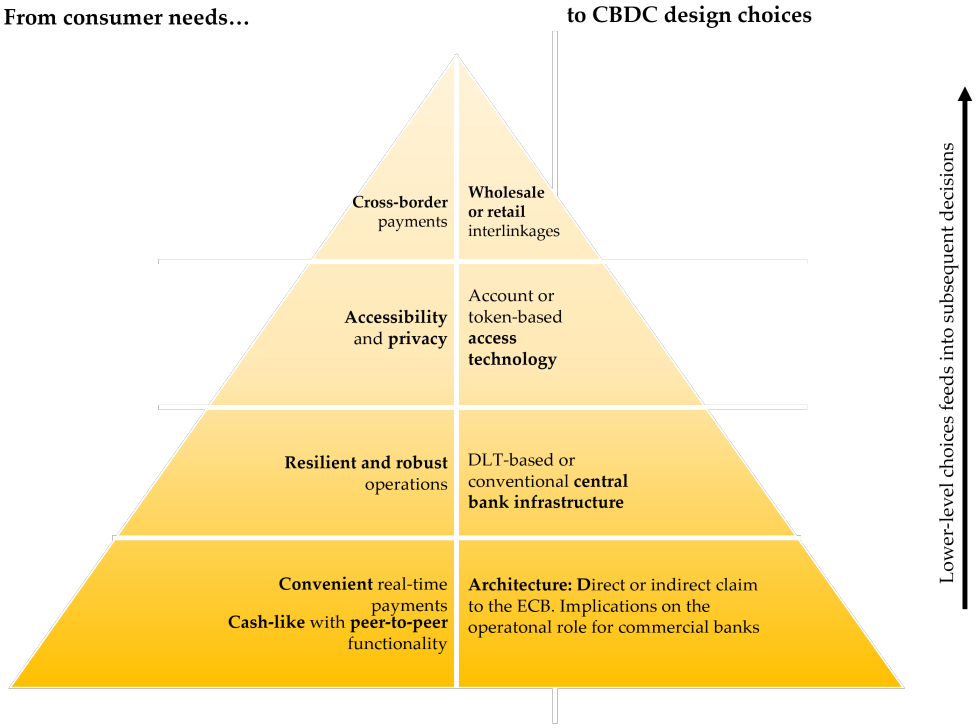


FIGURE 8: The pyramid shows the link between users' needs and CBDC design choices. Source: Elaboration from [1]

currency, thus ensuring a more solid foundation for commercial bank money. Additionally, the introduction of a digital euro could promote progress in the payment sector and increase Europe's sovereignty. Currently, there is no single cross-border solution for e-commerce or card payments in the euro area based on a European infrastructure.

Distribution Models

In determining the position of commercial banks following the introduction of the Digital Euro, the characteristics of the distribution model that will be adopted are crucial. The choice of these features is guided not only by the needs of the banking system but also by those of consumers. Figure8 represents how each requirement for the end user of the CBDC is associated with a specific choice in its design.

Starting from the base, the pyramid identifies the most important needs for users, ranging from the desire to have a currency with functionalities similar to cash, to the ability to use it for international payments, while also addressing issues of accessibility, privacy, and security. The needs for cash-like functionality and ease of use drive the authorities responsible for designing the CBDC to select a distribution architecture. The lower layer of the pyramid defines the operational roles of both the central bank and commercial banks. Currently, there are three possible architectural hypotheses, each of which is analyzed with a focus on the interaction between consumers, the central bank, and commercial banks. Each of the solutions under consideration is compatible with the structure of both a CBDC token-based system and a CBDC account-based system (for more details, please refer to the chapter on design choices).

In the "Indirect CBDC" model (Figure 9, top panel), the consumer holds a claim against an intermediary, and the central bank only tracks wholesale accounts. This configuration is similar to the way physical currency is distributed through the banking system, which retains its current role. Commercial banks remain responsible for all aspects of Know Your Customer (KYC) for the digital euro, meaning they handle the procedures to collect certain data and information about the users. They also manage retail transactions, in conjunction with various private payment systems (PSPs). In addition to offering the convenience of existing intermediary-based systems, the indirect model relieves the central bank of some responsibilities. However, the ECB does not record individual claims (intermediaries do that), only wholesale positions, so there is no record of the claims themselves. Consequently, it would be impossible for the central bank to honor requests directly from consumers without going through the intermediary's information. If the commercial bank where the digital euro deposit is held experiences financial stress, determining the rightful owner of the deposit could involve a potentially lengthy and costly legal process with an uncertain outcome. The extreme similarity of this architectural hypothesis to the current system of currency circulation reintroduces regulatory and oversight challenges, as well as the need for deposit insurance. On the opposite end of the

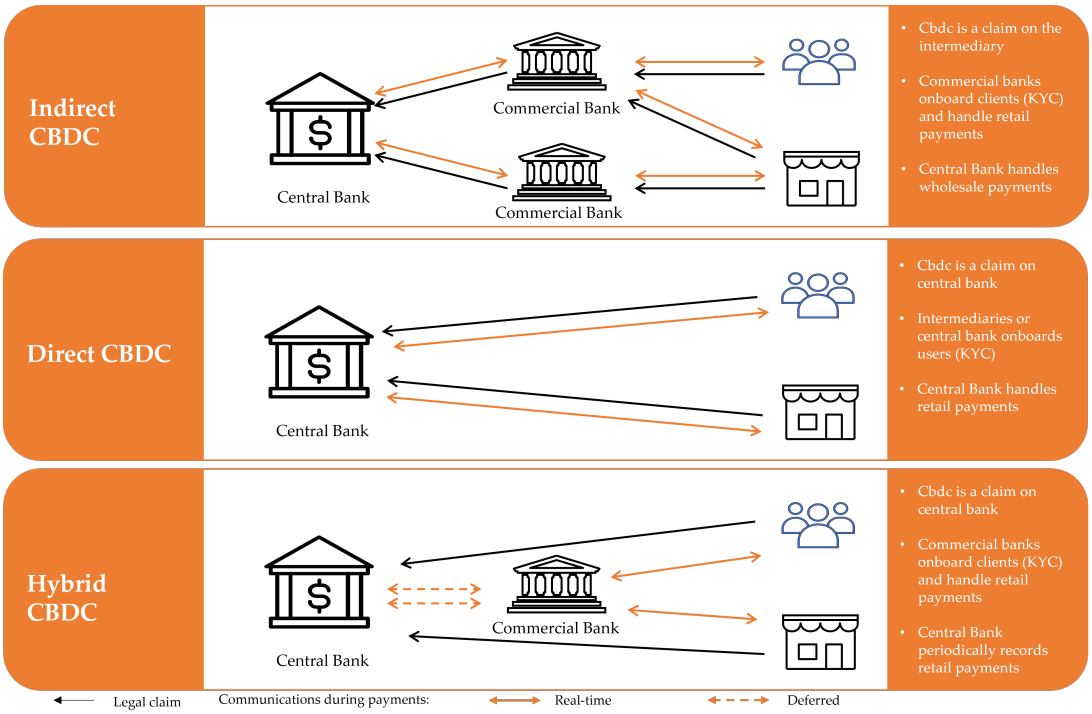


FIGURE 9: *Distribution models for CBDC. Source: Elaboration from [1]*

spectrum is the "Direct CBDC" model (Figure 9, middle panel), where digital currency represents a direct claim against the central bank, which maintains a record of all balances and updates it with every transaction. In this setup, the scope for commercial banks is reduced to KYC functions performed on behalf of the central bank. If these functions are fully internalized, it leads to complete disintermediation. Direct CBDC is an attractive solution due to its simplicity, eliminating reliance on intermediaries. However, this type of model comes with trade-offs in terms of reliability, speed, and efficiency of the payment system. It should also be noted that building and managing the technical infrastructure required to handle the entire volume of wholesale and retail transactions in CBDC is more compatible with the capabilities of the private sector, as seen in the case of existing credit card networks. Even if infrastructure challenges are overcome, the resulting CBDC might be less attractive to consumers compared to existing retail payment systems. Electronic payments must contend with connectivity interruptions or offline payments, which carry risks for intermediaries. It's important to note that it's the customer relationship, based on Know Your Customer (KYC), that allows intermediaries to accept these risks. Unless a central bank takes responsibility for KYC and due diligence toward the customer, which would require a massive expansion of operations beyond their existing mandates, providing this service would be challenging. In the middle ground lies the "Hybrid CBDC" model (Figure 9, bottom panel), an intermediate solution that incorporates features of both previously considered systems. It involves a direct claim to the central bank while still allowing intermediaries to manage payments. On one hand, similar to the "Indirect CBDC" model, KYC functions and the management of retail payments remain with commercial banks. On the other hand, as in the "Direct CBDC" model, the central bank is expected to periodically record user deposits. This results in one of the key elements of the hybrid CBDC architecture, namely legal coverage for deposits that keeps them separate from the commercial bank's balance sheets, allowing for portability. If a bank fails, CBDC holdings are not considered part of its available assets for creditors. The legal framework should also allow for widespread portability, giving the central bank the power to transfer retail customer relationships from a troubled institution to a fully operational one. The second key element is the technical ability to enable deposit portability. Since the requirement is to maintain payments when an intermediary is under technical stress, the central bank must have the technical capacity to restore retail balances. Therefore, it retains a copy of all user CBDC positions, enabling them to be transferred in case of technical failure. Hybrid CBDCs would have advantages and disadvantages compared to indirect or direct CBDC architectures. As an intermediate solution, they could offer greater resilience than indirect CBDCs but at the cost of a more complex infrastructure to manage for the central bank. On the other hand, hybrid CBDCs are still easier to manage than a direct CBDC. Since the central bank does not interact directly with users, it can focus on a limited set of core processes, while intermediaries handle other services, including the immediate confirmation of payments.

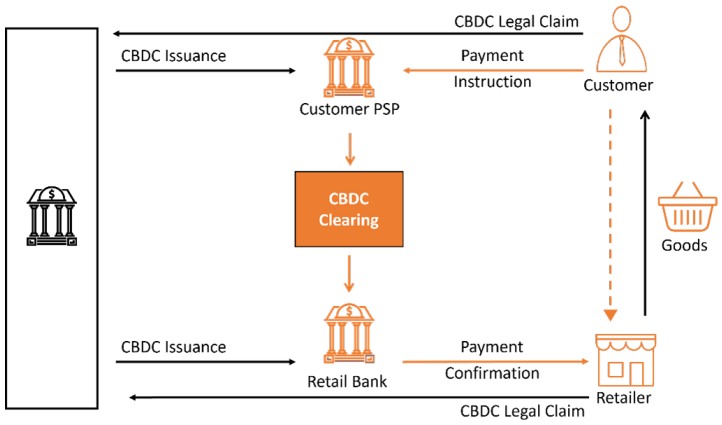


FIGURE 10: Hybrid CBDC functioning scheme

Commercial Banks and Hybrid Model

With regard to central banks that have issued retail CBDCs to date, all have adopted the hybrid model. Given this evidence, this configuration will be explored further as the most likely option for the distribution system to be adopted for the Digital Euro.

In the context of this distribution model for CBDCs, the technical role of commercial entities becomes a blend of seamless user interaction facilitation, intelligent transaction processing, and the creation of customer interface platforms. Ensuring that the CBDC is not only a secure and stable currency but also user-friendly and accessible requires meticulous development and maintenance of an infrastructure that aligns with the global objectives and regulations set by the central bank. Part of the committee involves the design and development of an interface that serves as the main point of interaction between users and the CBDC. These platforms must be designed with intuitive interfaces, ensuring they are navigable and accessible to a broad spectrum of the population, including those with limited digital literacy. Furthermore, safeguarding user data and transactions from potential threats becomes paramount, necessitating the integration of advanced cybersecurity protocols and continuous monitoring mechanisms. The management and processing of transactions, another vital component of the role, entail not only ensuring the technical capacity to handle large volumes of transactions securely and efficiently but also maintaining a ledger that is consistent with the central CBDC blockchain and compliant with data protection regulations. This requires the creation of systems capable of synchronizing with the central ledger while simultaneously safeguarding user data and privacy, possibly employing cryptographic techniques to securely process and record transactions. Furthermore, commercial entities must also take responsibility for ensuring that their technical infrastructure complies with the regulatory and operational standards established by the central bank. This includes adherence to technical standards, ensuring the validity and integrity of transactions, and complying with data management and privacy regulations, all of which collectively contribute to a uniform, secure, and reliable CBDC ecosystem. Additionally, proactive engagement in research and development initiatives that explore and integrate technological advancements, enhance transaction efficiency, and strengthen security protocols is crucial in maintaining the relevance and technological effectiveness of the CBDC. As introduced in the preceding paragraph, the hybrid model for the digital euro involves collaboration and integration between public and private sector entities. In such a system, the ECB retains control over the issuance and regulation of the digital currency, ensuring monetary stability and currency security. The impact of commercial banks and PSPs is present in the distribution and management of daily operations, such as creating digital wallets, processing transactions, and providing customer services. The hybrid approach aims to leverage the experiential knowledge and innovative potential of the private sector while ensuring that the ECB maintains strict control over the issuance of money to effectively conduct monetary policy interventions to safeguard financial system stability. The model envisions that users hold digital euros in electronic wallets, which can be used for making payments or receiving funds. Transactions, even though they occur in a digital format, would have legal legitimacy and security comparable to traditional physical cash.

In an increasingly digital world, the issue of protecting personal and financial data plays a crucial role. In the public consultation on the introduction of the Euro Digital, conducted by the European Central Bank (ECB), privacy emerged as one of the main concerns regarding the introduction of the CBDC, Euro. The choice of the hybrid model provides important assurances in this area. If customer identification (Know Your Customer or KYC) remains with commercial banks rather than the central bank, there is no change in the current data privacy model, provided an independent clearinghouse is used for interbank settlement in CBDC. However, if this is not

the case, the design of the Digital Euro could shift toward what has been implemented for the e-CNY CBDC in China, where the People's Bank of China (PBOC) has adopted a two-tier hybrid model. In this model, the PBOC is "responsible for issuance and provision, institution connectivity, and ecosystem portfolio management." Wholesale CBDC transfers are controlled by the central bank, leading to a loss of data privacy in favor of increased control over transactions and greater intervention effectiveness to prevent the "abuse of e-CNY in illegal and criminal activities, such as phone scams, online gambling, money laundering, and tax evasion." The compromise between control and privacy is a point every banking model architecture must grapple with, and the same holds for the hybrid CBDC. Fabio Panetta also addressed this issue in March 2022, stating the need to "balance the right to privacy with the public interest in combating illegal activities." EU regulations such as the GDPR, coupled with the results of the ECB's consultation, suggest that great attention will be paid to privacy management.

From a resilience perspective, the hybrid architecture is particularly advantageous due to its fundamental feature inherited from the direct CBDC model, where the CBDC represents a direct legal claim with the central bank. This is a fundamental turning point for financial system stability. Currently, if a commercial bank fails, the money deposited with it requires a form of deposit insurance to safeguard its value. In contrast, with the introduction of the hybrid CBDC model, the responsibility for the account lies with the European Central Bank, not the commercial bank where the account is held. Therefore, in the event of the latter's failure, the customer's Digital Euros remain unaffected and are transferred to another healthy intermediary (commercial bank or PSP), known as the portability of digital euro. With the implementation of this feature, users have the freedom to switch to another intermediary without the support of the previous one. As a result, users maintain uninterrupted access to their digital euro holdings and associated services, ensuring a smooth transition. Furthermore, an emergency portability procedure would allow access to digital euro holdings even in scenarios where the user's intermediary is unreachable for an extended period, and regular portability is not possible. Given all of this, the hybrid model offers potential solutions to concerns about CBDC data privacy while providing the financial stability benefits of a CBDC. It's clear why this is the preferred option for central banks. However, even if a hybrid model is the one launched in the initial CBDC issuance phase, there is no reason it cannot change in the future. One thing we can all be sure of is that this first wave of CBDCs is just the beginning, and it's the prelude to future innovations.

KYC and Retail Payments

The core functions attributed to commercial banks in the hybrid distribution model for digital currency are KYC onboarding and user-to-user payment management.

Regarding the first function, implementing Central Bank Digital Currencies (CBDCs) requires a delicate balance between technological advancements and regulatory compliance. KYC processes, essential for safeguarding financial transactions against potential illicit activities, play a more central role in the domain of digital currencies. This situation creates a dichotomy in which technological ease and adherence to regulations must coexist. Traditional KYC procedures, established within conventional banking and financial platforms, involve processes aimed at verifying customer identities, ensuring their financial activities align with legal and ethical parameters. The main pillars of KYC regulations are customer identity verification, transaction monitoring, and risk assessment. Adapting this framework to the CBDC context requires a fusion of traditional processes and digital technology. This adaptation is essential for aligning digital currencies with regulatory frameworks and safeguarding them from becoming vehicles for improper financial practices. The potential of the Digital Euro, as well as all other CBDCs, to facilitate fast and potentially anonymous transactions also exposes them to the risk of misuse, such as money laundering or funding illegal activities. In response to this risk, the evolution of KYC procedures requires advanced identity verification mechanisms, including biometric and multi-factor authentication, beyond traditional methods. This, combined with transaction traceability, can serve as a deterrent to financial criminals. However, overly stringent user recognition checks jeopardize the cash-like privacy features that are a major attraction for consumers. In this regard, exploring decentralized identity verification systems can bring benefits in terms of security and privacy by ensuring that identity data is not centralized, thereby reducing vulnerabilities. Regarding transaction traceability, the role of commercial banks involves the implementation and development of real-time monitoring and alert systems that detect and instantly report suspicious transactions, enabling authorities to take swift action against suspected illicit activities. Advanced data analysis, including Artificial Intelligence (AI) and Machine Learning (ML) algorithms, can be employed to identify patterns, trends, and anomalies in transaction data, helping detect potential money laundering or terrorist financing activities. The effectiveness of the Know Your Customer protocol cannot be separated from international harmonization. This is crucial to prevent countries with lighter regulations in this regard from becoming opportunities for facilitating illicit activities. This involves a dialogue to define global KYC standards and to facilitate unified prevention actions and mechanisms. For

example, the development of platforms for international sharing of information about illicit financial activities ensures that data related to threats, strategies, and technologies is disseminated to strengthen global defenses. While one of the attractions of digital currencies is the potential anonymity they offer, KYC regulations require a level of transparency. It is essential to strike a balance that allows users to enjoy privacy while maintaining control over transaction security. Additionally, the trade-off between privacy and security should consider the added element of accessibility. The effectiveness of KYC protocols by commercial banks should not be a barrier for users in accessing CBDCs. The widespread adoption of the Digital Euro is a fundamental goal declared by the European Central Bank, and the success of this operation depends on its ability to achieve a high degree of inclusivity. Therefore, especially concerning intermediary identity verification procedures, onboarding should not translate into bureaucratic or technological obstacles, even for the unbanked population.

Lessons from Bahamian Sand Case

To complete the analysis, an example of the CBDC program in the Bahamas is presented to evaluate its design choices and their consequences in terms of adoption, impact on the economy, and the involved stakeholders. The Bahamian Sand Dollar [34] is chosen as it represents one of the first fully operational CBDCs, making it possible to draw useful and applicable insights even in the context of the Digital Euro. The initiative in the Caribbean country is part of a payment system modernization aimed at advancing the nation's financial infrastructure. Key to this program is the desire to increase financial inclusion in a region where geographical barriers prevent a portion of the population from accessing payment services. The Central Bank of the Bahamas has placed great emphasis on the potential of this initiative in disbursing subsidies to underbanked or unbanked individuals, which could serve as inspiration for the ECB. Architecturally, the Sand Dollar is issued by the Central Bank of the Bahamas (CBOB) and utilizes blockchain technology. Individuals and businesses can access and use the Sand Dollar through a digital wallet available via a mobile application. Payment transactions are processed through a platform created by NZIA Ltd., a technical service provider contracted by CBOB to manage the technical aspects of the CBDC project. Since prepaid cards or digital wallets contain CB money and are based on DLT, transactions can be processed directly between CBOB electronic wallets. The CBDC in the Bahamas also has an international dimension, as it integrates with the global financial system. Specifically, a collaboration with Mastercard has led to the launch of a prepaid card closely connected to the Sand Dollar digital wallet, facilitating users in making transactions across the Mastercard network. Consumers can choose between a Tier 1 eWallet with a 500 $ limit and a monthly transaction limit of 1,500$ and a Tier 2 eWallet with an 8,000$ limit and a monthly transaction limit of 10,000. The expected outcome for residents regarding the Sand Dollar is that everyone can use a CBDC with a legally convenient, cash-like experience that resembles physical currency. This includes the development of offline features, which are not yet complete but aim to address communication disruptions between the various islands that make up the Bahamas. The design of these features aims to allow users to make a predetermined dollar amount of payments and update electronic wallets once communication with the network is restored. The desire to have cash-like characteristics, such as strong user privacy protection for low-value transactions, led CBOB to define reduced KYC requirements. In fact, no official identification documents are required for Tier 1 e-wallets. In the context of the Sand Dollar, commercial banks act as stabilizers and facilitators, playing a fundamental role in mediating transactions and providing support to users. In addition to offering digital wallet services to manage Sand Dollar reserves, commercial banks have integrated digital transactions into their existing services, ensuring a complete customer experience. They also ensure that every transaction remains within legal and compliance boundaries, strictly adhering to anti-money laundering protocols and counter-terrorism financing regulations. Finally, commercial banks play a crucial role in educating and guiding customers on how to effectively and securely use digital currency. The Sand Dollar infrastructure, although applied to an economic and cultural context different from that of the Eurozone, can provide valuable insights for the ECB and European commercial banks. Specifically, for the Central Bank, the aspect of financial inclusion promoted by CBOB is particularly relevant, translating into the goal of reaching low financial literacy populations and considering the possibility of using the CBDC as an effective vehicle for economic subsidies. On the intermediary side, an interesting insight could be the structuring of eWallets into 2 Tiers with associated limits, as well as the high degree of interaction between private sector actors and the Central Bank.

Challenges in Governance and Risk Management

The framework outlined in the previous paragraph identifies commercial banks as the chosen institutions for the distribution of the Digital Euro. This means that these banks must perform the conversion function from commercial bank money to Digital Euro. Consumers will need to withdraw money from their payment, savings, or deposit accounts to obtain Digital Euros. Consequently, every Digital Euro that is distributed causes an outflow of

	Rate (%)
Deposit facility rate	-0.50
ESTR	-0.57
EA 10-year government AAA rated bond yield	-0.37
EA 10-year government benchmark bond yield	0.14
Overnight deposit rate (households)	0.01
Overnight deposit rate (non-financial corporations)	-0.03
Markit iBoxx MFI bonds yields	0.12

TABLE 1: Interest Rate environment in Q3 2021. Source: Elaboration from [10]

deposits that reduces the commercial banks' holdings by the same amount, and therefore, the banks' balance sheets shrink. Although holdings in Digital Euros can also be converted back into accounts held at banks, positions in CBDC are held outside the traditional banking system. Such a configuration raises particular concern among intermediation sector actors. The main points of uncertainty that commercial banks must prepare to face in conjunction with the introduction of the Digital Euro are related to liquidity risks, disintermediation, and the specter of bank runs. The impact of each of these risk components is linked to the degree of CBDC adoption that will be found at its launch, i.e., the demand for Digital Euros. This variable will largely depend on the features and context in which the digital euro is introduced, including interest rates. The extent to which the public decides to convert bank money into digital euros will determine the size of deposit outflows for the banking sector and could therefore affect banks' ability to intermediate credit to the private sector. Analyzing the impact of introducing the CBDC on the banking intermediation sector first requires an assessment of the potential demand for digital euros. Such an estimate can be developed from data from field surveys, the estimation of macroeconomic variables such as the elasticity of substitution between CBDC and bank deposits, and considerations based on assumptions about the Digital Euro's features. Although uncertainty about the assumptions underlying these scenarios is high, some of the proposed scenarios consist of a bank deposit outflow of 5% to 10% of banking assets [24] and 20% of household and non-financial deposits. The demand for a digital euro will depend heavily on its design features and the prevailing environment at the time of its introduction, including interest rates and the existence of alternative forms of money. Some features of the digital euro design, such as remuneration, could largely encourage or discourage adoption: clearly, an unremunerated CBDC would be less attractive in a positive interest rate context. Likewise, it is plausible that greater availability of alternative forms of money might weigh on the demand for a digital euro. These factors, combined with ease of use and the ongoing trend towards a more digital economy, create a multitude of possible demand scenarios that are hard to estimate or calibrate. The interaction between the ECB and commercial banks will also play a pivotal role in determining the actual adoption rate of digital currency. Based on an analysis conducted in [10] on behalf of the ECB in "Central bank digital currency and bank intermediation," two distinct scenarios of digital euro demand are considered, plus a third scenario considering the introduction of a holding cap, i.e., the case of a limited supply. The choice of these scenarios is not based on their likelihood but is dictated by the desire for a comprehensive analysis. The first two scenarios feature an increasing degree of CBDC demand: the first (A) considers a "demand limited to retail payments," while the second (B) considers massive adoption, resulting from the digital euro being heavily used as a means of payment and store of value. These scenarios illustrate the demand for a digital euro under standard market conditions, interest rate environment in Q3 2021 is the reference. In an environment of negative interest rates, an unlimited (i.e. unfettered) supply of an unremunerated digital euro would likely result in (almost) unlimited demand. This is because the digital euro would offer a higher degree of security and a more attractive yield than traditional deposits.

In **scenario A**, it is assumed that the digital euro only partially replaces other retail payment methods. Specifically, in the reference analysis, the CBDC is used in place of banknotes and overnight deposits in accordance with what was highlighted in the previous paragraph. The proposed substitution rates for retail payments by households are: 50% of the value of banknotes used for retail payments, 25% of the value of transactions paid with cards, and 75% of the value of transactions settled with other payment methods. The same values are also adopted for non-

		Households	NFCs	Nonbanks	Foreign	Total
Scenario A	**Assumptions**	• 50% substitution of banknotes used for retail Payments • 25% substitution of cards • 75% substitution of other (paypal etc)	Same proportion of banknotes and deposit substitution applied to household	No demand for retail Payments	Demand only by non- residents visiting the euro area	
	Overall Demand	**278**	**89**	**0**	**120**	**488**
	From Overnight Desposits	120	60	0	0	**180**
	From banknotes	158	30	0	120	**308**
Scenario B	**Assumptions**	• 70% of banknotes • 50% of overnight deposits	• 70% of banknotes • 50% overnight deposits	90% of overnight deposits	• 80% remaining banknotes held by non-residents • Deposits: 90%	
	Overall Demand	**3127**	**1383**	**776**	**2204**	**7490**
	From Overnight Desposits	2594	1283	776	1699	**6352**
	From banknotes	533	100	0	505	**1138**
Scenario C	**Assumptions**	3000 per euro area individual (incl. 50% substitution of banknotes)	Envisaged design for no significant use of D€ by NFCs	Envisaged design for no use of D€ by non-banks	Demand only by non – residents visiting the euro area	
	Overall Demand	**1028**	**0**	**0**	**120**	**1148**
	From Overnight Desposits	647	0	0	0	**647**
	From banknotes	380	0	0	120	**500**

TABLE 2: Estimated Digital Euro demand across Scenario A,B and C. Source: Elaboration from [10]

financial corporations (NFC). As for non-residents, it is assumed that the demand for digital euros replaces only banknotes, related to their visits to the euro area.

Overall, based on the assumptions for scenario (A), the potential demand for the digital euro amounts to approximately 490 billion, divided between 370 billion of domestic demand and 120 billion of foreign demand. **Scenario (B)** depicts an intense use of the digital euro as a store of value coupled with a greater utilization in retail payments. In this scenario, most of the demand for the digital euro is driven by the preference to have access to a secure currency as it is issued directly by the central bank. Firstly, it is assumed that both households and NFC replace 70% of cash transactions. A full substitution isn't anticipated as a lingering preference for holding cash, especially among certain demographic categories, is considered. Moreover, estimates show that banknotes are used for illicit transactions. Secondly, it's assumed that households and NFC replace 50% of their deposits with the digital euro. Contrary to scenario A, which considers only demand for retail payments, it is presumed that the replacement of deposits by non-banking financial institutions (NBFI) and non-residents is proportionally larger (90%), stemming from a significant demand for the digital euro as a store of value by these sectors. This estimation is motivated by the assumption that these sectors would always have a higher preference for holding the digital euro, allowing them to access - like banks - the safety of the central bank's currency to maintain their liquidity. The final estimate for scenario B amounts to a total of 7.5 trillion euros, with 5.3 trillion stemming from domestic demand. Households would represent the largest share of domestic consumption, with 3.1 trillion euros (Figure 11). In terms of substitution of instruments, most of the overall digital euro demand would come from overnight euro deposits. The last scenario features a holding cap, assumed to be 3,000 € based on the latest communications on the matter . The cap is applied solely to residents while non-residents visiting can hold digital euros exclusively for retail payment purposes. In this scenario, neither the NBFI nor the NFC would be authorized to accumulate balances in the digital euro. However, merchants could receive CBDC payments via a functionality that would instantly transform such payments into bank deposits. Assuming a complete

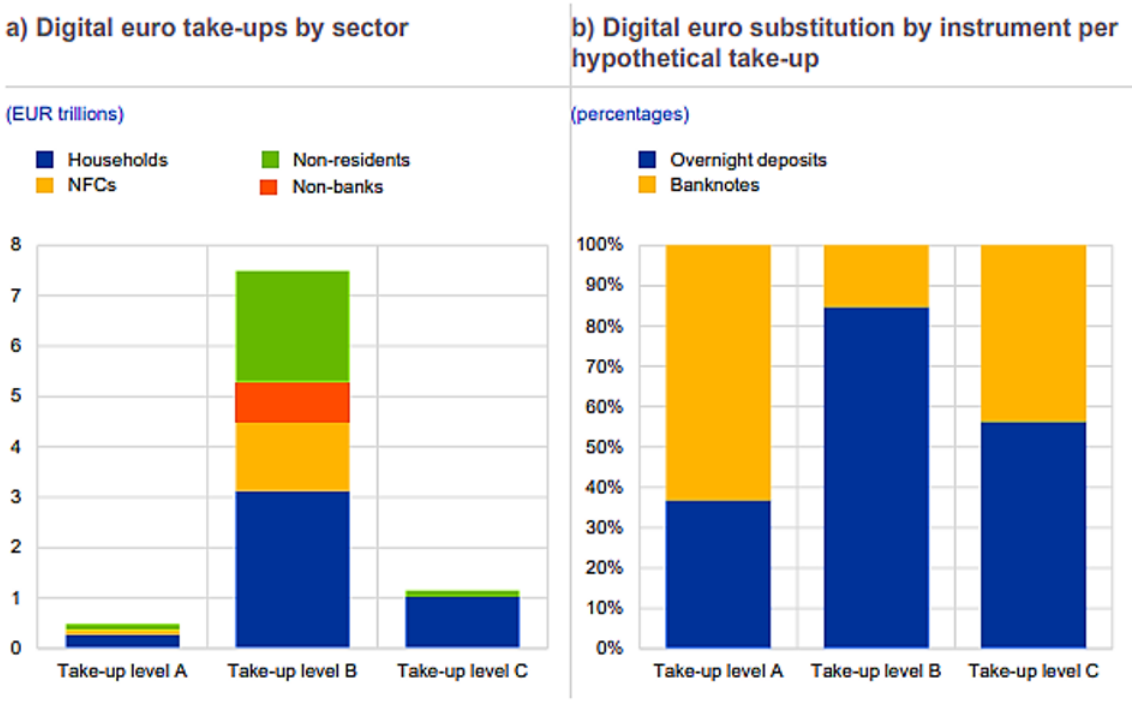


FIGURE 11: The histogram shows the expected Digital Euro adoption by sector and instrument through scenarios A,B and C. Source: [10]

exhaustion of the 3,000-euro limit by each of the approximately 340 million inhabitants of the euro area results in a total demand of 1.03 trillion euros. Demand from visiting non-residents (i.e., only for retail payments) is calibrated to be around 120 billion euros similarly to scenario A. Thus, the overall digital euro demand translates to about 1.15 trillion euros as shown in Figure 11. Assuming, as in scenario A, that 50% of the banknotes held by households in the euro area is replaced by the digital euro (about 380 billion euros), the remaining amount would imply a substitution of 12.5% of household deposits. This is a rough estimate, as it is realistic to consider that not everyone will exhaust the imposed limit. A change in both directions of the holding cap by 1,000 euros would alter the deposit substitution by approximately 2% of the total (almost 1% of total banking liabilities). Starting from a fixed share of banknote substitution, any modification of the holding cap will, by assumption, only be reflected in a substitution of the digital euro for the same, generating a variation of about 340 billion euros. Table 2 summarizes the estimated Digital Euro demand across the three scenarios. The scenarios presented suggest, in the most extreme case, a demand for Digital Euro of 7.5 trillion euros. This scenario is associated with an 18% bank deposit substitution rate. The results of the analysis are subject to a series of caveats. Firstly, the data on which the analysis is based will not exactly match the balances at the time a digital euro could actually be introduced. Secondly, the substitution rates are based on plausibility considerations that currently cannot be verified against any data. Thirdly, these figures are obtained by considering only a static substitution of deposits at the aggregate level of the euro area. They do not include general equilibrium effects, such as reactions from banks, which could change the terms and functionality of the services they offer, nor potential interest rate adjustments that could result from a decrease in deposits as a source of bank financing. Furthermore, they do not reflect any potential central bank reaction aiming to offset undesirable effects arising from the introduction of a CBDC on the direction of monetary policy, which could lead to the creation of new bank deposits. Given these approximations, it is still possible to draw some insights from the scenario analysis that depend on the regulatory choices of the European Central Bank that will accompany the introduction of the digital euro. In fact, these decisions will have an impact at the level of the entire economic system involving both users, i.e., households and businesses, and financial institutions. For the former, the demand for Digital Euro is linked to whether it is perceived solely as an alternative payment method to cash and card or as a real reserve of value and how this perception will change financial habits. From the financial intermediation side, the limits that will be imposed at the regulatory level by regulators will determine the scope of the impact that replacing traditional deposits with Digital Euro will have on the balance sheets.

CBDC Distribution Channels and Impact on Banks' Balances

Once the users' perspective regarding the demand for CBDC is examined, the implications of a digital euro on bank balances are also explored, focusing on the impact it could have on commercial banks. Since a digital euro can potentially replace part of bank deposits, it is possible to distinguish between four different adjustment channels. The balance sheet mechanisms show that, except when the introduction of a digital euro is accompanied by a reduction of excess reserves or banknotes, the central bank should inject liquidity to meet the demand for CBDC. The examination of the implications on bank balances of the Digital Euro assumes that the Central Bank can fully compensate for the effects of CBDC demand on the banking sector, in line with the current literature's opinion. It's essential to highlight that heterogeneities within the banking system mean that the impact of a digital euro can vary significantly among credit institutions. Considering the setup of the hybrid model, it's assumed that banks mediate the distribution of the digital euro. The digital euro can be distributed either by converting from banknotes or by reducing reserves with the Eurosystem. Commercial banks can also obtain additional reserves by increasing loans or selling assets. From the ECB's perspective, the first two possibilities represent a swap from existing liabilities, i.e., bank reserves or banknotes, to the digital euro. The other two options, however, constitute an expansion of assets as the issuance of CBDC exceeds the reduction in reserves or banknotes. The choice by commercial banks is linked as much to customer preferences as to ECB decisions. Depending on the extent of deposit substitution, banks, because of profitability and regulatory considerations, may prefer a specific adjustment path and adapt their balance sheets accordingly. Finally, European authorities play a key role as they are responsible for the quantity of digital euro in circulation. Going into the details of the distribution channels:

- Replacing banknotes with the digital euro equates to an exchange between two types of Eurosystem liabilities, with no implications for bank balances. Banks would simply act as distribution agents: cash holders would return banknotes to the Eurosystem and exchange them for digital euros, leaving the Eurosystem's other assets and liabilities intact.
- Banks reduce reserves held with the Eurosystem by an amount equal to the loss on deposits, without further affecting other items on the asset side of their balance sheets. Reserves decrease as banks use them to acquire digital euros from the ECB to transfer to their clients in exchange for deposits. Other bank assets remain unchanged. In this case, there is a liability swap for the ECB, with the digital euro covering the reduction in bank reserves. Individually, it's foreseeable that commercial banks would engage in interbank loans to cover the demand for digital euros from customers, which might differ among banks, considering the fact that reserves are distributed unevenly in the market.
- Banks replace deposits converted into digital euros with an increase in borrowing from the Central Bank, without further changes in other balance sheet items. Driven by the lack of the necessary amount of reserves or a preference to maintain a certain level of them, banks might be willing to borrow additional reserves to meet the demand for digital euros from their customers. In this case, the ECB would replace the funding capacity lost by banks due to the transformation of deposits into digital euros. This solution results in an extension of the ECB's balance sheet size equivalent to the substitution of deposits, preventing a contraction of bank credit to the economy.
- Banks can obtain reserves by selling assets to the Central Bank from their portfolios or on behalf of their clients. In the event of an asset purchase, the ECB pays the seller through reserves. Banks can then use the newly created reserves by converting them into Digital Euro as demanded by their clients. The assets sold by the banks can come from the bank's own portfolio, or on behalf of their clients, thereby creating new deposits for customers in this case. This solution accompanies the loss of bank deposits with a reduction in bank assets.

The use of each of the four channels presented is subject to specific limits: the reduction of reserves at the Central Bank is subject to the constraint of the aggregate level of excess reserves at the ECB; the increase in debt to the Central Bank is feasible as long as the requesting commercial bank does not exhaust its guarantees; while the sale of assets is constrained by the availability of suitable assets for the ECB to purchase. Such considerations can be further detailed when evaluated in light of the potential CBDC adoption scenarios hypothesized at the beginning of the chapter. Estimates for scenario A, where the Digital Euro is used solely for retail payments, suggest that the banking sector could meet CBDC demand when compared to the quantification of the aggregate limits of the 4 distribution channels. The higher level of demand associated with scenario B, with a replacement of deposits of over 6 trillion euros, opens up the need for a significant expansion of the Eurosystem's balance sheet. Only the use of an optimal combination of all four channels could be compatible with an orderly adjustment process (graph 5). However, the distance from the limit of overall feasible adjustment would be reduced, especially considering that the adjustment channels are not mutually independent from each other. Finally, regarding sce-

nario C, characterized by the presence of the holding cap for the CBDC, each of the channels would meet the demand associated with a cap of up to 5000 euros per resident. In this case, the wide absorption margin of the demand between the adjustment options would also be consistent with the expectation that such absorption would not translate into aggregate balance sheet dynamics that would reduce the profitability of banks and their ability to provide credit to the economy. This data shows how the economy would be able to support the distribution of a larger amount of Digital Euro compared to the limit proposed by the regulatory authorities; however, in this case, the previous considerations come into play regarding the effects of reducing deposits for commercial banks and related problems in terms of reducing their financing capacity. Consequently, defining a holding cap cannot ignore the search for a balance between the aim of a widespread diffusion of the CBDC and that of maintaining the stability of the European economy.

Simulated Banking Responses to CBDC Demand

When assessing the impact of the introduction of the Digital Euro on banks' balance sheets, it is crucial to understand that the shift from bank deposits will also have effects on the LCR (Liquidity Coverage Ratio) and the NSFR (Net Stable Funding Ratio). Together, LCR and NSFR are liquidity measures addressed in the Internal Liquidity Adequacy Assessment Process (ILAAP) and to some extent also made public to bolster confidence in the banking industry from both investors and end users. Both measures must be complied with at 100% on a daily basis. All supervised institutions have internal buffers reflecting their risk appetite framework in terms of liquidity risk. Both will undergo changes with the introduction of a Digital Euro incrementally: the introduction of a Digital Euro will cause the average decrease of both LCR and NSFR, as the higher the amount of Digital Euro positions allowed, the greater the drop in both LCR and NSFR. The LCR is a short-term liquidity measure oriented to cash flows under stress conditions, with detailed regulatory parameters and assumptions. The Non-Maturing Deposits (NMD) that would be directly impacted by the limits of a Digital Euro generally have an outflow rate of 5%. Therefore, simply looking at the reduced NMD amount (less outflows) is too shortsighted. Credit institutions invest volatile and highly liquid positions in liquid assets. The LCR defines them as High-Quality Liquid Assets (HQLA) that increase the ratio by market value - (a slight) haircut. For compliance reasons, credit institutions must always apply a conservative approach in calculating this liquidity indicator. Therefore, the Digital Euro holding limit is binding for the LCR calculation. While a limit of, for instance, 1000 would mean only a slight reduction in LCR, a limit of 3000 and beyond would involve liquid but stable portions of NMD. As a result, the total amount of available HQLA will drop significantly. This is why the following chain holds true:

$$HQLA \downarrow \rightarrow LCR \downarrow$$

$$\text{LCR} \rightarrow \textit{with P\&L} \downarrow \textit{Rating} \downarrow \rightarrow SREP \downarrow \rightarrow \textit{minum equity} \uparrow \rightarrow \textit{P\&L} \downarrow$$

So, credit institutions will have to make a choice: accept lower levels of LCR or offset the loss of NMD and HQLA by resorting to other funding sources, typically more expensive. Impact on the Net Stable Funding Ratio: The NSFR follows a balance sheet approach with a one-year horizon. NMDs usually provide 95% of the available stable funding factor at any given time. HQLA as an asset counterpart only requires the (small) haircut as stable funding needed (unless it is encumbered). A decrease in NMDs results in an immediate and significant drop in the NSFR. The chain of effects is as follows:

$$NSFR \downarrow$$

$$\text{NSFR}\downarrow \rightarrow \textit{with P\&L} \downarrow \textit{Rating} \downarrow \rightarrow SREP \downarrow \rightarrow \textit{minum equity} \uparrow \rightarrow \textit{P\&L} \downarrow$$

While the LCR can be adjusted with liquidity management techniques, achieving higher levels of NSFR is much more complex and expensive. As a result, credit institutions will either have to accept lower NSFR levels or compensate for the loss of NMDs with other funding sources and a new financing strategy. This latter option will always involve the use of capital market instruments, to which some institutions have little or no access. To examine how banks might handle the potential outflow of deposits due to the conversion of euros into CBDC, consider a model where a bank aims to minimize funding costs, subject to specific constraints. First, a liquidity constraint assumes that a bank maintains voluntary reserves beyond regulatory requirements. Moreover, long-term funding, both secured and unsecured, and central bank long-term funding secured by non-HQLA assets, such as additional credits (ACC), do not negatively impact liquidity ratios.

Highlighting the context of bank constraints and preferences, the simulation suggests that, for low levels of CBDC demand, the vast majority of banks can meet the demand using their reserves, without excessively impacting their HQLA buffers. Note that the initially outlined scenarios, including deposit flows in the order of 180 billion euros and 647 billion euros, can be roughly compared to an outflow of 4% or 8% of deposits from households and non-financial firms. For high CBDC demand scenarios, banks would have to navigate through a more complex financing strategy. With an estimated substitution of 6.4 trillion euros of sight deposits, equivalent to an outflow of 60%, only 37% of the CBDC demand could be accommodated through the use of own reserves. Additional central bank funding proves cru-

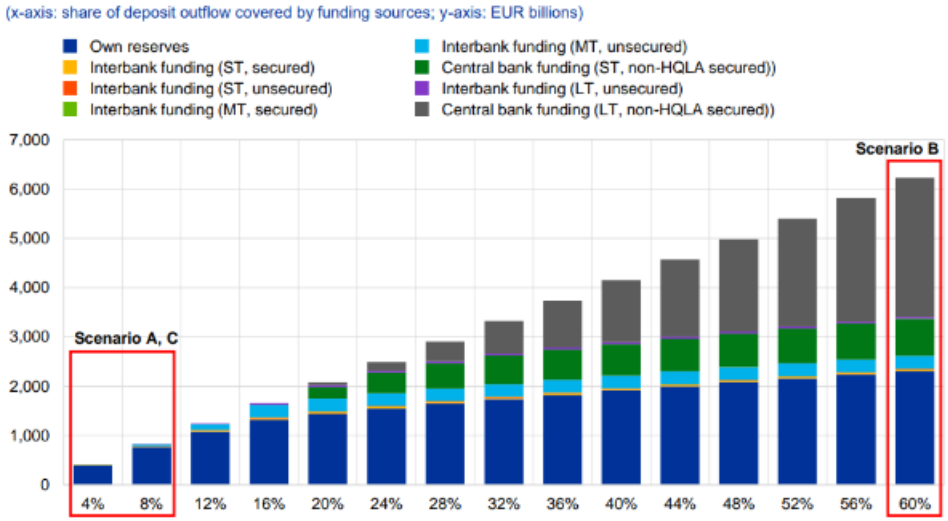


FIGURE 12: Bank Balance sheet re-optimisation. Source: [10]

cial to mitigate the impacts of such a substitution of deposits with CBDC. In summary, the analysis suggests that the introduction of a digital euro in a period with high reserves, like in the post-pandemic context, would allow banks to manage CBDC demands up to a certain point using their own reserves. However, heterogeneity among banks in terms of liquidity preferences and availability of reserves and guarantees might generate heterogeneous responses to CBDC. Liquidity regulation and voluntary liquidity reserves limit the total reserves banks are willing to use or sell to facilitate CBDC conversion. Therefore, central bank policies need to be adequately equipped to address these challenges.

Potential Bank Runs Across the Economy

In addition to any implications for bank intermediation in normal times, a digital euro could influence the severity of bank runs as it would provide citizens with a super-safe asset at relatively low storage costs. Large-scale withdrawals of insured bank deposits have occurred recurrently in the past. During times of stress and depending on its design, the role a digital euro could potentially play as a store of value could become especially pertinent as it is a more easily accessible super-safe asset with lower storage costs, compared to cash . Therefore, some authors have suggested that CBDC might "open a highway to bank runs" and that "deposits would migrate more easily towards the CBDC during times of stress". Two models are used to discuss the potential implications a digital euro might have for the severity of system-level bank runs. Firstly, a model to simulate bank runs is applied to past episodes of bank runs across the economy to assess what would have occurred if a digital euro coexisted with cash. Simulations are run under various limits on the use or remuneration of CBDC. Secondly, building on an extension of the Diamond and Dybvig (1983) model that incorporates cash and CBDC, the paper explores further potential implications, such as the impact the CBDC might have on welfare in the event of a system-level bank run. The proposed setups share features that make them suitable for considering the severity of system-level bank runs. Firstly, both setups consider that individuals can convert their bank money into cash or CBDC. Secondly, the central bank's liabilities are used solely as a store of value, and CBDC is generally preferred due to technological superiority. Thirdly, both models allow us to assess the impact a digital euro can theoretically have on the severity of bank runs along at least two dimensions: the magnitude of a bank run, understood as the share of total bank deposits that are withdrawn during a bank run; and the speed at which a bank run occurs, defined as the time it takes to withdraw a certain share of bank deposits. In the models used, parameters are calibrated in such a way that the simulated withdrawals match the deposit outflows recorded during recent bank runs in Greece (2015) and Cyprus (2013). The introduction of a digital euro impacts the maximization of depositors' expected return in two ways. Firstly, depending on the selection and calibration of usage limits and remuneration, a digital euro can provide a low-cost alternative to liquid holdings and might also allow for "unlimited" withdrawals. Secondly, it is assumed that each citizen substitutes a portion of their deposits with the digital euro before the onset of a bank run (i.e., substitution in normal times). An unconstrained demand for CBDC would lead to an increase in the scale and speed of a (simulated) system-level bank run. Compared to the scenario with no digital euro, the increase in the scope of bank runs in the potential Digital Euro A and B scenarios, hypothesized at the beginning of the chapter, is reflected in a larger share of deposit withdrawals, while the increased speed of bank runs is reflected in the shorter time required to reach a certain number

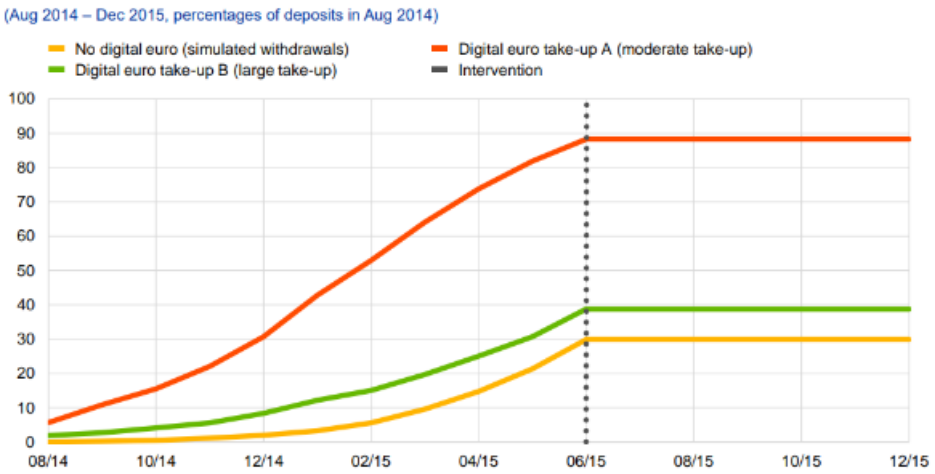


FIGURE 13: Bank Balance sheet re-optimisation. Source: [10]

of deposit withdrawals (Figure 13). The magnitude and speed of the simulated bank runs are more pronounced in the CBDC context, as it's presumed that such a conversion is subject neither to holding costs nor a convertibility limit. Compared to Scenario B, the magnitude and speed of the simulated bank runs are greater in Scenario A, as it involves a lesser substitution from bank deposits into digital euro before the bank run occurs (respectively 500 and 7,500 EUR). This reveals a trade-off: the lower the demand for CBDC under standard market conditions (i.e., before the bank run), the greater the level of aggregate deposits that can potentially be withdrawn in crisis times. Based on its level, the definition of a holding cap would act counter to the amplification of the scope and speed of the simulated bank runs across the economy. As illustrated in panel a) of Chart 14, a 3,000 euro cap on individual holdings in CNDC in Scenario C would more than offset any adverse impact a digital euro could potentially have on the scope and speed of the simulated bank runs across all sectors. This is because the demand for a digital euro in normal times (i.e., before the bank run) is such that the aggregate level of available deposits that can be withdrawn in the event of a run extending across the whole economy is lower than in the scenario without a digital euro.

Technological Infrastructure and Innovation Challenges

Digital Euro Infrastructure: a Two-Tier Model

The success of integrating the CBDC into the economy requires that both public and private partners draw upon their respective areas of expertise within the payment ecosystem to develop an infrastructure that is efficient, user-friendly, and secure. One crucial aspect will be the need to incorporate interoperability features.

For a CBDC system, interoperability guarantees the ability for funds to flow easily between payment systems, facilitating its integration within a broader payment system. Interoperability encompasses a range of features, from the technical infrastructure implemented to common legal, regulatory, data, and messaging standards that all stakeholders involved in the distribution chain of the CBDC central banks, commercial banks, and payment service providers share. The fundamental aspect of interoperability is achieving "standardization" to ensure compatibility between them. The emphasis on interoperability is motivated by its significant contribution to the adoption, innovation, and efficiency of the Digital Euro for end-users. When payment systems are not interoperable, there is a risk of fragmentation, resulting in the spread of "closed systems" that cannot interact with each other, creating inefficiencies for users. Another dimension of interoperability in the context of the general CBDC infrastructure is cross-border payments. In this regard, the configuration considered most suitable for building an infrastructure that ensures the mentioned attributes is a two-tier system. In this system, central banks issue CBDCs to commercial banks, payment service providers, and fintech companies, which are responsible for distributing digital currency to consumers and merchants. Individuals and businesses can manage their CBDC balances held with the ECB and registered with the ECB, making payments through their private sector service providers. These providers, including Payment Interface Providers (PIPs) and Ecosystem Service Interface Providers (SIPs), could be banks, financial institutions, or non-financial institutions, provided they have the appropriate regulatory status and authorization to offer such services. All transactions would be settled on the central bank's ledger in real-time, on a one-to-one basis, without netting or clearing with other transactions and with finality.

This model ensures that banks can maintain their existing relationships with their customers while conducting compliance checks such as KYC (Know

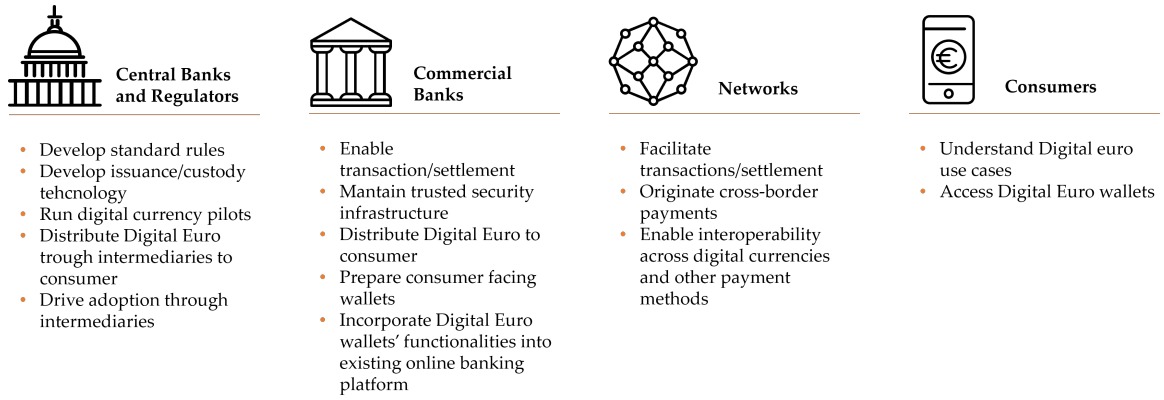


FIGURE 14: Key points for an adequate preparation to the introduction of Digital Euro Source: Elaboration from [25]

Your Customer) and AML (Anti-Money Laundering). In the digital world, a two-tier system can be implemented using public-key cryptography, allowing the central bank to outsource the complexity of managing digital certificates for CBDC tokens to a set of potentially regulated and authorized entities.

Preparing for the Digital Euro: Digital Wallets

According to the latest statements from the European Central Bank, users may access digital euro services through the apps and online interfaces of their banks or payment service providers, or through a digital euro app provided by the Eurosystem. In both cases, the design of the wallet is of great importance as it serves as the primary interface between the CBDC system and the end user. In the near future, the success of CBDC wallets will depend largely on their ease of use and accessibility. A CBDC wallet should be as intuitive as modern digital banking or mobile payment apps to ensure rapid adoption. Features such as QR code scanning, NFC payments, and biometric authentication could become standard for both wallet authentication and transaction validation. A key factor in the attractiveness of wallets is their ability to seamlessly integrate with other financial platforms. This includes connecting to investment portfolios, enabling automated bill payments, or interfacing with peer-to-peer lending platforms. The ability to operate within a broader financial ecosystem will be a determining factor for their long-term profitability. An additional level of innovation could involve integrating regulatory functions suggested by regulators directly into the wallet. This would allow for automatic tax deductions, monitoring of suspicious transactions, or compliance with international sanctions as integral components of advanced CBDC wallets. Furthermore, in addition to basic transaction functionalities, future CBDC wallets may offer a variety of in-app financial services, from microlending to insurance products, directly within the wallet interface. These services could provide opportunities for commercial banks to expand their offerings. One controversial point in wallet design is the choice between hot and cold wallets. A hot wallet is a digital wallet always connected to the internet. It can be of two types: "custodial" and "non-custodial." In the first case, the private keys to one's CBDC are also held by the bank or payment system providing the wallet service. In the second case, the user directly controls their private keys, allowing them to access their tokens as needed. This solution simplifies usage but is more vulnerable to malicious activities. A cold wallet or hardware wallet is a wallet that doesn't require an internet connection for access. With these wallets, you can store your private key, necessary for access, offline, eliminating the risk of data theft. While providing greater security and independence, it would be almost impossible to recover if a private key were lost, and it could be complex for less experienced users. As CBDC projects evolve and become more widespread globally, the design, functionality, and integration of digital wallets will undoubtedly become more sophisticated. These real-world examples provide an idea of the current direction and potential future of CBDC wallet design:

1. **DCEP** (Digital Currency Electronic Payment)
    - **Wallet Features:** Users can download a DCEP wallet app on their smartphones. The app allows users to link their bank accounts, enabling them to convert a portion of their bank savings into digital currency.
    - **UI/UX:** The wallet's interface resembles many popular contemporary digital payment apps in China, such as Alipay or WeChat Pay. Users can scan QR codes to make payments or receive funds.
    - **Offline Functionality:** The DCEP wallet allows touch functionality, meaning users can transfer digital yuan to each other by simply touching their phones together.
2. **Sand Dollar**
    - **Wallet Features:** Once users register,

they get a digital wallet that can be managed through a mobile app. Users can add funds, check balances, and make transactions through this app.

- **UI/UX:** The Sand Dollar app is easy to use with clear icons and instructions for making payments, checking balances, and managing user settings.
- **Integration with Merchants:** Businesses can receive payments in Sand Dollars through a point-of-sale system, making integration into the current business environment easier.

3. **e-Krona**
    - **Wallet Features:** While the exact design specifications were still under exploration, the Riksbank stated that users would have an e-Krona wallet, which could require a mobile app or a card.
    - **Security Features:** The e-Krona system is designed with an emphasis on security to ensure the wallet and transactions remain safe from potential threats.
4. **Project Jasper**
    - While not a full CBDC, Project Jasper was a collaborative research initiative between the Bank of Canada, major Canadian banks, and other stakeholders to explore the concept.
    - **Wallet Features:** Although primarily an experiment, the system envisioned users having digital wallets capable of managing, issuing, and transferring digital CAD.
    - **Clearing and Settlement:** One of the primary explorations in Project Jasper was real-time gross settlement (RTGS) using distributed ledger technology, suggesting potential future integrations of CBDC wallets with instant settlement mechanisms.

Funding and Defunding Wallets

As mentioned before the possibility for users to access their Digital Euro wallets through their banking app can translate into a huge opportunity for commercial banks themselves, yet exploiting this opportunity requires a smooth incorporation of the CBDC wallets into the existing bank or PSP interface and an agile interation between both of them. Per its latest (18 October 2023) [9] publication on Digital Euro the European Central Bank deep dives into these matters with particular regards to the funding and defunding functionalities. Funding modalities are key to a seamless payment experience, particularly in view of holding limits. Funding sources could be either a commercial bank account or cash. Although not mandatory it is expected that a large part of Digital Euro users will exploit the convenience of linking their digital euro account to a designated commercial bank account for funding purposes. This choice would allow to receive a payment, even if the amount to be received raises the digital euro balance above the holding limit. The excess amount would be transferred automatically to the linked commercial bank account. Users would also be able to set a threshold for this automatic transfer that is lower than the holding limit. This particular feature is called waterfall functionality. On the other hand users would not need to prefund a digital euro account before making payments. If there are insufficient funds in the digital euro account, the shortfall could be transferred immediately from the linked commercial bank account (reverse waterfall functionality). An individual would be able to choose whether to benefit from the waterfall or reverse waterfall functions or both, many commercial banks and PSP have already introduced this possibility in their platforms. Waterfalls combine funding/defunding and payment processing in a single operation, with no or very limited impact on the processing time for the user. If there is no linked commercial bank account or waterfalls are not enabled, the user would be responsible for keeping the digital euro account balance within the holding limit, increasing the need to manually fund and defund the account and the possibility of transaction failure. A user with multiple commercial bank accounts would be able to use any of them to fund the digital euro account. However, only one commercial bank account could be designated for the waterfall and reverse waterfall functions.

The commercial bank or the PSP managing the digital euro account does not need to be the same one managing the linked commercial bank account, furthermore other developments could be added so that and digital holdings in an automated way. Taking into considerations the offline functionalities which are expected for the Digital Euro users would be able to fund and defund their offline holdings when the device has an online connection, either directly or via a banking terminal. The waterfall and revers waterfall mechanism would not be available requiring offline not to exceed the prefunded amount. A range of funding modalities would be available to suite different user preferences, as an example users who wants focus on keeping control of their Digital Euro spending with a monthly budget could automatically top up their digital euro account to the desired amount while others could prefer to pay in digital euro without having to prefund their digital euro account, drawing the liquidity from their commercial bank account as required exploiting reverse waterfall End users would be able to fund and/or defund their digital euro holdings on a 24/7/365 basis. Funding/defunding via digital

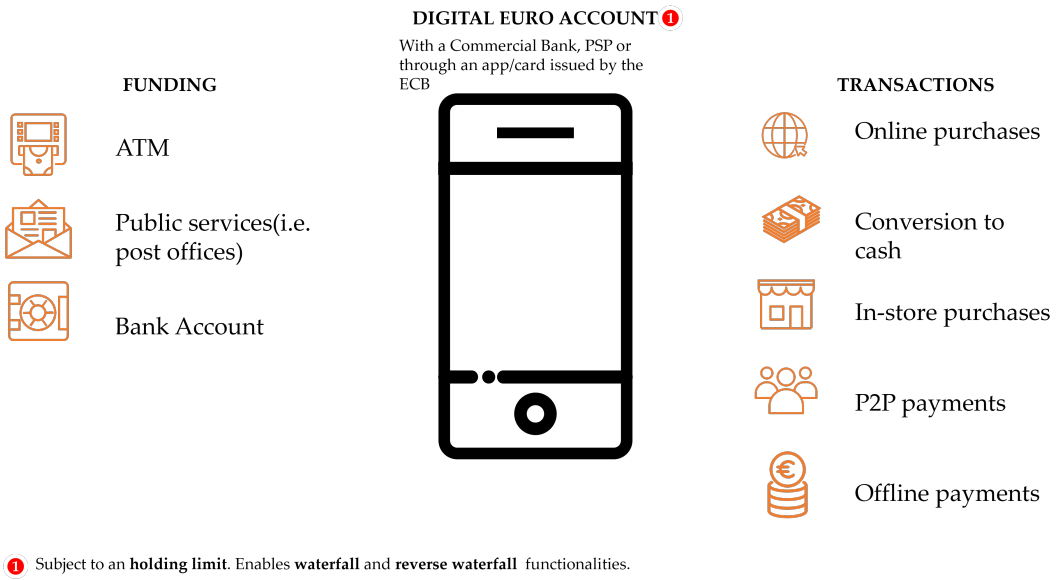
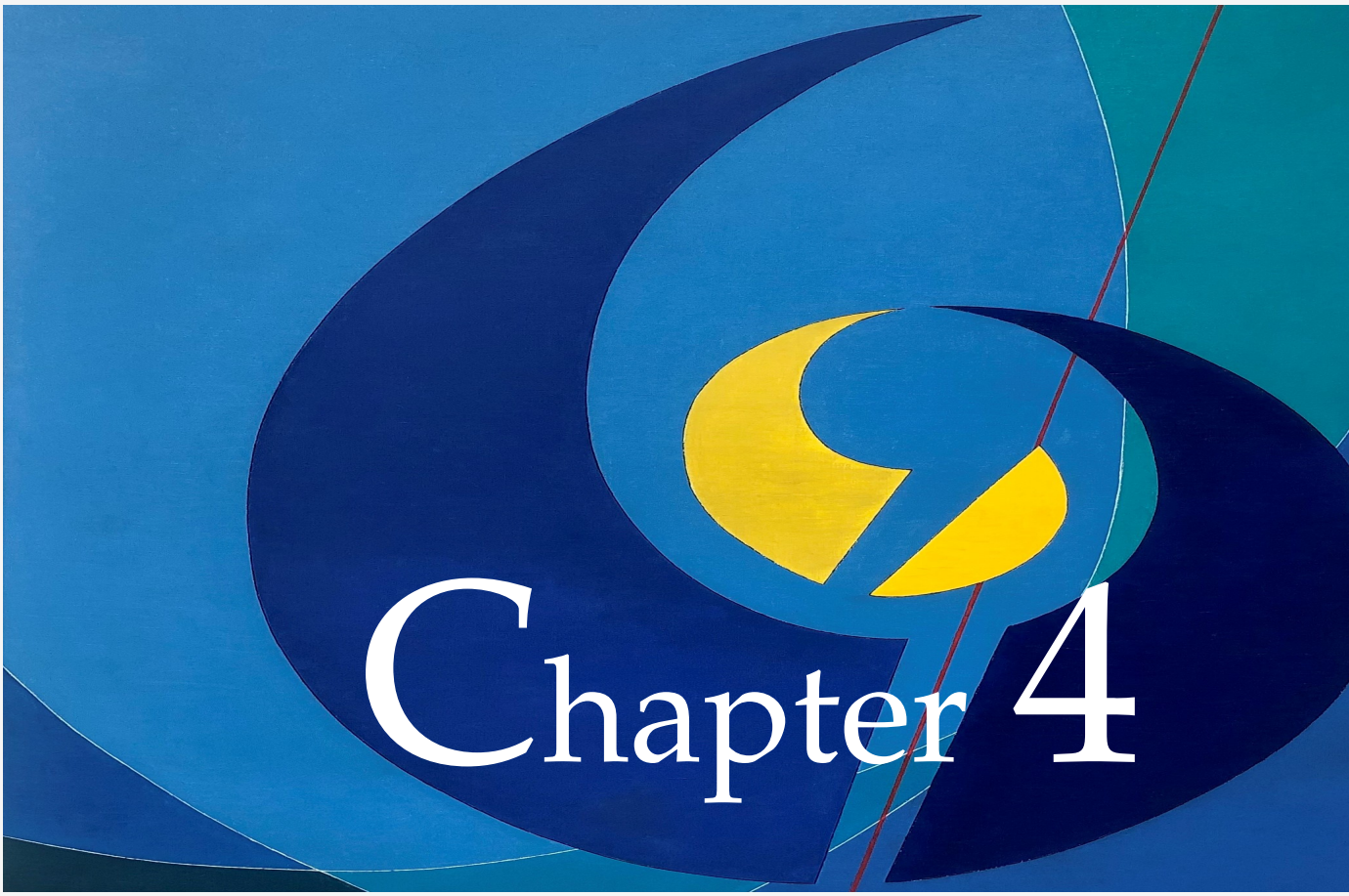


FIGURE 15: Digital Euro account summary

payment means would be possible anytime. Funding/defunding via cash would be possible at least at times when a PSP is already providing cash services.



Distribution Models, Risks and Security

Distribution Models, Risks and Security

The introduction of a CBDC can be considered as a new foundation for the payment system, as well as a potential solution to link different payment systems, both legacy and new. However, the CBDC must secure several significant advantages over available options due to the abundance of private digital currencies. In this regard, an important topic to discuss is the possibility of introducing offline payments, through which several goals can be achieved such as financial inclusion, universal access and privacy. Nevertheless, offline payments can have some risks typically linked to their intrinsic characteristics. Moreover, introducing a CBDC could entail dealing with new technologies, critical operations, and, therefore, also new security and operational risks. In fact, central banks and other actors in a CBDC ecosystem will need to face up to this increasingly complex cyber threat landscape as the risks can arrive from different sources. Nowadays, the world's three major economies are designing payment systems for their digital currencies. However, China, US and Euro Zone are at a different level in the path leading to the introduction of a digital currency. Overall, the emergence of CBDCs has both advantageous and disadvantageous consequences for financial systems. For these reasons, their implementation must be approached with careful consideration, especially in light of the specific characteristics of each nation's financial system.

Different Payment Systems: Steps for the Adoption of a New Payment Systems and Online Versus Offline Solutions

In a rapidly digitizing economy, a CBDC is considered a valid option in order to maintain the centrality of safe and trusted central bank money. Its introduction can be considered as a new foundation for the payment system, as well as a potential solution to link different payment systems, both legacy and new. But, precisely because of the vast supply of private digital monies, **it is critical for the CBDC to ensure certain major benefits** with respect to current options; if users lack incentives then they could show limited interest. Therefore, its success should not be taken for granted and a full understanding of what really matters for users is advisable.

For this reason, in the Euro Area the ECB conducted a study [29] to discuss the possible drive acceptance of a new digital payment method. The targeted users were divided based on their use and approach to digital payments in three categories: *the general public and tech-savvy, merchants and the underbanked people*.
Discussions with the ***general public and the tech-savvy*** indicated that, in order to encourage engagement with any new digital payment method, this method will novel benefits that simplify daily life. This can be translated into a set of critical characteristics reported in the list below:

- **Universal acceptance**: this is the most important feature, since it implies acceptance across the Euro Area (and beyond), in physical and online stores and for any kind of purchase in terms of size.
- **Instant, contactless and open person-to-person payments**: an important feature of the above universal acceptance can be reconducted to the convertibility of the digital wallet in already existing platforms or devices used by payers and payees.
- **One-stop solution**: allowing to combine multiple payment methods into one, reducing the need for multiple cards and personal identification numbers. A plus would be the possibility to set customizable reporting functions, such as spending limits or spending reminders, ensuring a good financial control over the wallet.
- **Easy to use, secure, reliable and fast**: this is an important topic since it goes from security in terms of protection of personal data from fraud and hacking to secure and reliable authentication for payment. For younger users in the specific, biometric verification such as fingerprint, face or iris scans, are indicated as being highly desirable.
- **Cost-efficiency**: all these functionalities cannot be introduced at the expense of higher costs compared to the actual payment solutions. Indeed, it is preferable for the digital wallet to carry no cost or at most very low fees.
- **User-friendly, fast and easy onboarding**: the new digital wallet should be easy to use also

because of the possibility of integrating it with existing wallets which users already own and use.

- **Privacy**: protection of personal data should always be granted. Not only that, but privacy settings should also be flexible in order to users to choose the desirable privacy level. In the specific, under this study it was found that users are more concerned for exposure to bank advertising than for the visibility of their transactions.

Other features can be added if considering other type of users. Here, it may also be interesting to analyze the potential preferences of other segments, like merchant and under-banked people.
At present, ***merchants*** offer a wide range of payment methods such as cash, credit cards, debit cards, online payment methods (e.g. paypal), mobile-to-mobile payments, banking apps (e.g. Revolut), bank transfer and pre/post sale invoicing. Essentially, for this category what matters is the possibility to satisfy any customer preferences over payments and, for this reason, **customer demand** emerged as the main driver to the acceptance of a CBDC. Moreover, satisfying clients by offering the latest payment method has advantages for the image of their business; merchants do not underestimate the potential, since **a company seen as technologically up to date** can attract new client segments.
Operationally, a payment system should be **easy to integrate** in the current business and offer critical features. One of them is certainly the **speed of transaction**: the new digital payment must be high-performing, must provide instant and reliable payments and must ensure instant access to the funds. This characteristic could be really attractive as merchants could improve the quality of the shopping experience without sacrificing an easy cash management. Technical reliability backed up by agile and **good customer service** is also important for merchants. Finally, a **good level of integration with their day-to-day business activities, existing payments and accounting systems** is another critical features that digital currency should have in order to be appealing to merchants. It is important to highlight that, also for this category, the cost-efficiency of the new digital wallet should be taken into account: in the specific, we refer to the possible financial charges and fees, as well as the need to invest in additional technology and the time and effort required to get up to speed.

One of the main goal a central bank has in mind to drive the CBDC introduction in the economy is financial inclusion. Indeed, a part of the study was dedicated to understand the perspective of the ***unbanked/underbanked and offline population***. Clearly, this group presents level of mistrust towards financial institutions and, for this reason, they prefer to be in control over their wallets. Therefore, for this population segment the main driver is represented by the fact that this new digital payment should **act like cash** as much as possible; it must be secure, free of charge and easy to use, without requiring any technological skills. To address their preferences, the new digital payment system should allow people to make low-value private payments (like cash), to make instant payments, to have full control of their expenses, to withdraw money using a card, to make automatic payments, to have a monthly statement, and to have the possibility of offline use without an internet connection[29]. Another important aspect to consider is that generally this group choose to have control over their wallets by using cash; with a CBDC this surely could change, and they might depend on others to set up, use and account for the way they use the new method, and might also need help to resolve issues or get their money back. For this reason, a **robust customer service** can help, particularly in the beginning, to ensure the right support in terms of set up and problem solving.

Offline Payments

An important topic to discuss is the possibility of introducing offline payments as a design option. First of all, it can be of interest to point out the definition for an offline payment with CBDC: it is defined as a transfer of retail CBDC value between devices that do not require connection to any ledger system, often in the absence of internet or telecoms connectivity [5]. In fact, this could bring a CBDC closer to its substitute cash, therefore this feature benefits from central banks special attention. For example, a survey conducted by the BIS Innovation Hub [5] shows that 49% of central banks surveyed consider offline payments with retail CBDC to be vital, while another 49% deemed it to be advantageous.
Thus, many central banks view offline capability as a potential way to achieve other objectives such as **financial inclusion, universal access, payment system resilience and privacy**. Most of them are actually studying the best way to implement such functionality, since it carries also different complexities due to the number of technologies involved, the security and operational considerations and risk management design option to be chosen.
At the root of the need for offline payments with CBDC, there is the topic of **resilience**. Indeed, at all times the overall payment system should be able to operate, with or without connectivity. Indeed, actually both individuals and businesses are exposed to issues in the digital payment system which can make them unable to pay or receive payments, for example after a natural disaster. With a CBDC, this should not be the case. Moreover, there are still parts of the world in which internet or network connectivity is unavailable or unreliable; an offline CBDC can overcome this lack of developed communications infrastructure, reaching people living in every corner of the world.

A CBDC can also enhanced **financial inclusion**. Broader than that, also **social and digital inclusion** are positively impacted. A CBDC should be created ensuring that everyone can use it and thus having an universal acceptance. For example, where individuals are unable to access payments using mainstream options such as smartphones or an internet connection, or for those without bank accounts, reliable internet access or access to mobile phones, a CBDC can be an alternative. Moreover, a CBDC can be designed to be inclusive regardless of background and digital competence: from the youngest to the eldest in society, as well as people with specific physical and mental impairments should have the access guaranteed. This may require a variety of technologies, since no single technology can include everyone. Since offline payments are sometimes perceived as the (almost) perfect substitute of the present-day use of cash, they should guarantee the same user experiences, like **privacy or anonymity**. Even if a total level of anonymity is not possible for many reasons (first and foremost for ALM/CFT and KYC/KYB requirements) , it is true that with an offline wallet users are disconnected from a ledger system, implying more privacy than with online payments. The cash resemblance feature is strongly tied to the topic of **universal access**, particularly because in many countries cash is the only option which offer such possibility. **Scalability** can be fostered or damaged by different choice in the financial architecture of the offline feature: indeed, central banks must found the right balance between the positive effect of a decrease in the load on ledger systems and the negative effect of the increase in data size,thanks to the decreasing overall load on ledger . Finally,offline payments could potentially incur **lower transaction costs** than online systems and may allow CBDC systems to target use cases that involve small transaction values. Making digital peer-to-peer (P2P) and person-to-business (P2B) offline payments can be fostered also because of the minimum intervention by a third party. On the other hand, consequences following this design choice can be higher **implementation and operational costs** of maintaining and upgrading the supporting offline infrastructure as well as the **cost of acquiring and distributing user devices and merchant point-of-sale terminals**.

As can be seen in figures 16 and 17, solutions providing offline payments functionality can be of three types: **fully offline, intermittently offline and staged offline**.

Risks

Offline payments can have some risks from **cybersecurity threats** to **operational risks**, typically linked to their intrinsic characteristics. The most common are:

- **Counterfeiting via physical breaches**: it consists of a physical attack on the device. In particular, the attack can be carried out by cloning or manipulating the value-form of the digital wallet, held in a purse on a user digital device such as smartcard or in a storage on a mobile phone.
- **Counterfeiting via cryptographic protocol analysis (cryptoanalysis)**: by construction, offline payments may be the target for this type of attack; indeed, the transfer between purses is protected by cryptography. For this reason, the cryptographic keys used to protect the payment transfers may be recovered and reverse engineered, generating fake massages to users and counterfeiting value.
- **Side-channel attacks**: also this type of attack targets the cryptographic keys used to ensure transfers between purses. In particular, if an attacker with sufficient equipment can recreate these keys, he can exploit information leaked by the device and counterfeit them. Therefore, it occurs when an attacker tries to access data inside a device by attacking it from the outside.
- **Fault-inducing attacks**: this type of attack can be performed by inducing faults during cryptographic processing by placing it under stress through some external method, e.g. heat or radiation. Crypto-analysts may then be able to deduce key values by comparing outputs.
- **Third-party device compromise**: this risk derives from the fact that offline payments may need to use a third-party device, such as smartphones or feature phones, over which central banks and vendors may have limited control. This means that malware attacks may occur targeting software-based purses. Moreover, third-party devices may be compromised due to security weaknesses created accidentally by users and then detected and exploited by threat actors. One solution can be designing these third-party devices to limit the amount of information they leak during processing.
- **Device obsolescence**: older devices may become obsolete when they are no longer supported by the solution provider or when relevant security or other updates cannot be provided. This can create space for attackers to operate.
- **Double-spending**: in the specific, this risk refers to situations where the same offline value is spent a number of times. This can be due since it is not always possible to performe an instantaneous online check to verify that the payer still has the amount on the digital wallet.

TRANSFER MECHANISM DESIGN	
Online third-party validated solutions	transactions would be made online and would be validated by a third party. There can be multiple advantages with this solution: first of all, transparency of transaction data will be ensured to intermediaries for ALM/CTF purposes. Secondly, it leaves room for flexibility in other design decisions related to the digital euro. However, it will be important to further investigate solutions to increase its resilience to connectivity outages.
Offline peer-to-peer validated solutions	the privacy of low-value proximity payments is guaranteed within limits set by legislation. The time of market implementation for this solution is more uncertain because of its dependence on technological innovation, regulatory changes and security risk tolerance.
Potential peer-to-peer validated solution for online payments with no third party	It is the more experimental options, it will allow remote payments but transactions cannot be checked ex-ante.

FIGURE 16: Transfer Mechanisms proposed by the Bis Innovation Hub - Source [5]

- **Money laundering**: as previously explained, not all the offline transactions can be recorded by a ledger. For example, in order to increase the CBDC resemblance with cash, central banks may decide to allow small transactions to be performed without identification or full KYC checks. In these cases, offline payment solutions could be abused for money laundering techniques such as *smurfing*, where large transactions are broken up into many small transactions to avoid detection.
- **Lost of value**: offline value can get lost for different reasons. For example, the value is lost since the user device is lost and thus the offline value is no longer available to the user. This can be a dangerous situation since the value could, in theory, be spent by someone who gains possession of the device. Another case is when the user device can be broken; the user may forget about the CBDC wallet on its device; a transaction is torn, i.e. value has left the prayer purse and has not been received by the payee purse. For this last case, central banks have the option to introduce the possibility of interrupting the transaction.
- **Fraud**: in particular, for instant payments where the payment value is instantly settled on the payee, fraudsters may operate in order to divert funds or goods through social engineering attacks. These last are oriented to create false messages to convince users to send money or even by impersonating third parties known by the users. Thus, the ability to identify payees may be necessary to prevent this type of fraud, even if this comes at the expense of a lower level of privacy. Since fraud is one of the main risks, the European Union has also extensively focused in legislative terms. Indeed, to identify and prevent fraud, the proposal for a regulation of the European Parliament and of the European Council on the establishment of a digital euro regulates the general mechanism for the detection and prevention of fraud. Specifically, **Article 32** of the proposal [21] states that **the European Central Bank may facilitate the fraud detection and prevention tasks carried out by payment service providers under Directive 2015/2366** by establishing a general fraud detection and prevention mechanism for digital euro transactions carried out online. In this way, it will be possible to ensure the smooth and efficient operation of the digital euro. This mechanism shall assess in real time the fraud risk exposure of digital euro transactions carried out online for the exclusive use of payment service providers before the transaction is introduced into the digital euro settlement infrastructure. Moreover, it shall help payment service providers to detect fraudulent transactions in digital euro payment transactions that have been settled and carried out online. This general fraud prevention and detection mechanism may be managed directly by the European Central Bank or by support service providers designated by the European Central Bank. For the purposes of this Article, payment service providers shall provide the fraud detection and prevention mechanism with the necessary information. Payment service providers shall also implement appropriate technical and organizational measures, including state-of-the-art security and privacy measures, to ensure that the support service is not able to directly identify users of the digital

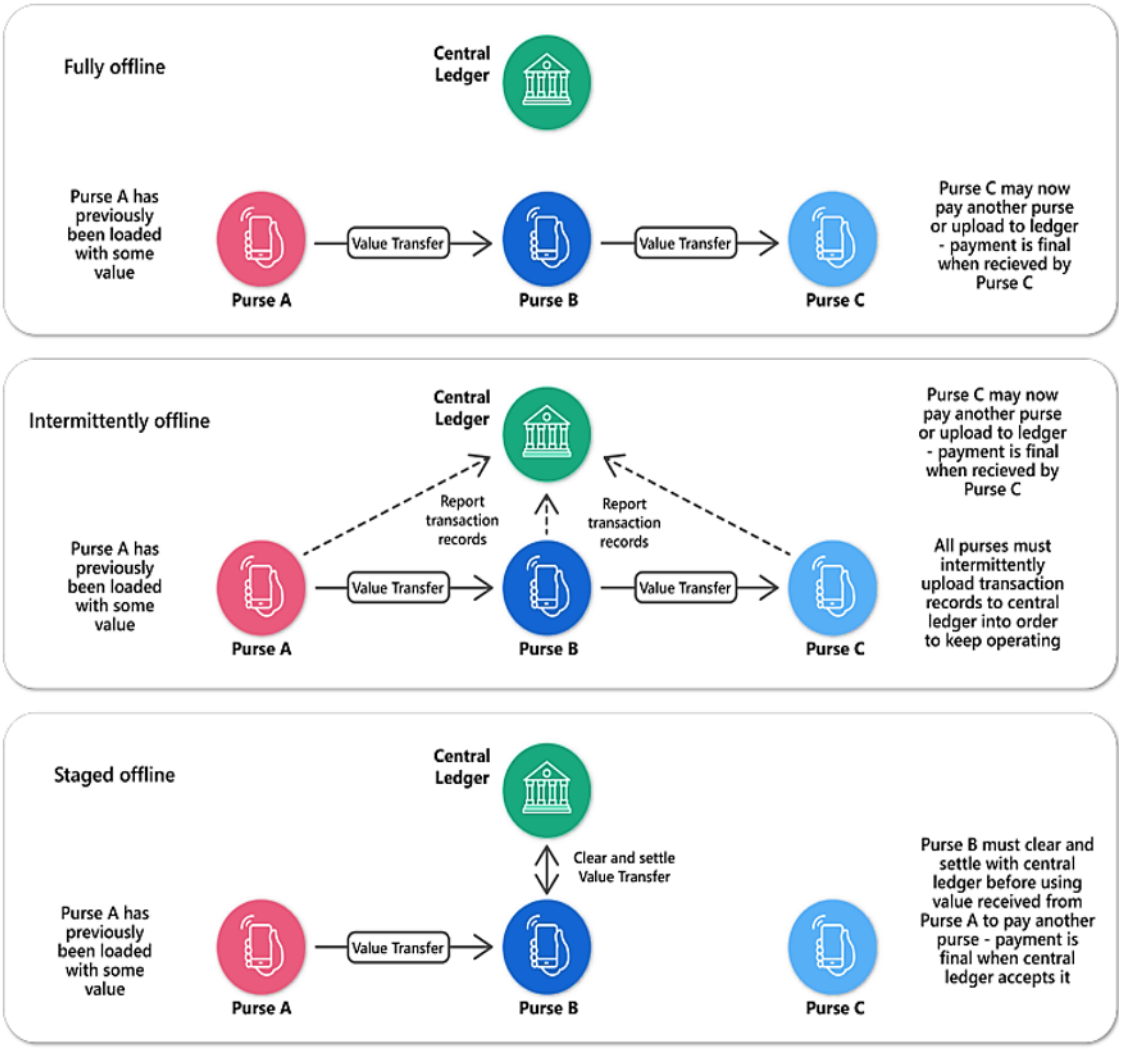


FIGURE 17: Modes of offline payments - Source [5]

euro on the basis of the information provided to the fraud detection and prevention mechanism.

Risk Management

To counterbalance these risks, a range of both **technical and non-technical risk management measures** would need to be implemented. The first important criterium is that **CBDC design should limit the scope and the scalability of an attack**: if an attack is successful, its effect should be limited in order to avoid the spread to other purses or other devices. Another important feature is to introduce methods to detect that a breach has taken place and, secondly, **to isolate the compromised purse**: this can be done by downloading block lists of compromised purses to other purses or tightening offline risk checks to manage breaches. Finally, **systems should be upgraded and stress-tested regularly** in order to counteracting any new type of attack.

To have an idea, in a study [5] the BIS Innovation Hub has proposed a simplified model of the risk management components based on five layers:

1. At an **user device level**, devices must be capable of securely storing and processing data and cryptographic keys for some defined and extended period of time.
2. **Purse**: the purse software must secure stored data, including the value-form and cryptographic keys.
3. **Value transfer protocol**: this protocol must ensure that the value-form cannot be used more than once, excluding the double-spending problem. A way to implement this protocol is through cryptographic processes.
4. **Counterparty purse**: on the other side of the transaction, a counterparty purse could implement risk rules to limit the amount of value that can be exchanged, limiting the damage in presence of a rogue device. Programs can be install in order to even block suspicious transactions involving that device.

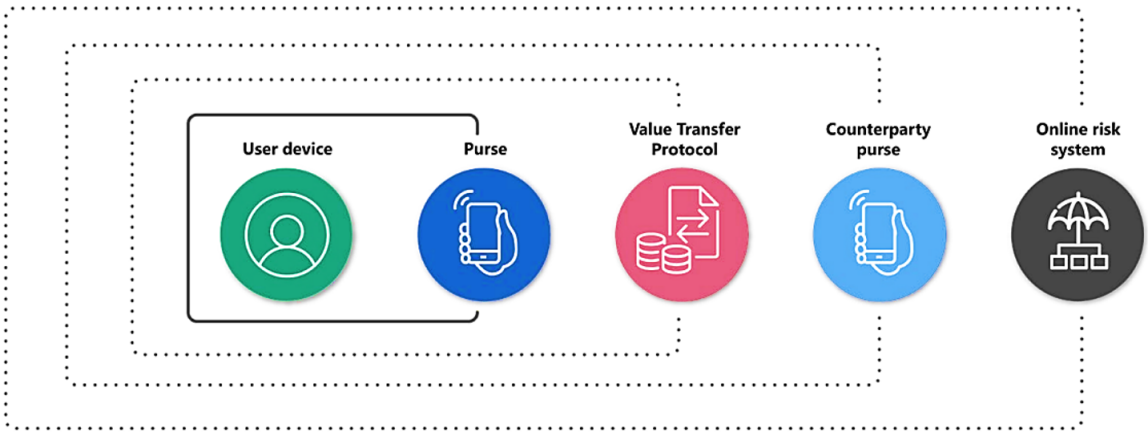


FIGURE 18: A simplified view of the layers of risk management components - Source [5]

5. **Online risk systems**: risk systems are needed to monitor the state of the system, including the amount of value flowing through it. This allows to collect transaction records, clear transactions, update risk parameters and refresh cryptographic keys on offline devices.

These are general indications, since there are no perfect technologies. Despite that, the above mentioned criteria should be enshrined within the design of the solution to ensure that system breaches can be managed.

Comparing Proposals to Structure the Payment Systems in Case of a CBDC: Digital Euro, Digital Dollar and E-CNY

We discuss now practical and real examples in order to better understand how the world's three major economies are designing their payment systems for the introduction of digital currencies.

China, US and the Euro Zone are at a different level in the path leading to the introduction of a digital currency. The **People's Bank of China is already a leading experimenter** and attaches great importance to the research and development of digital fiat currency. Over the last eight years, China has conducted pilots in at least ten regions; moreover, PBOC has also tested the E-CNY during the 2022 Beijing Winter Olympics. On the contrary, the **US is still at an initial stage**: there are some proposals and some pilot experiments but the discussion is still open. The reasons may be different but generally they can be reconducted to the specific characteristics of their financial market. In particular, with the digital yuan, the PBOC is actually responding to the phenomenon of cashless economy and to the duopoly of Alibaba and Tencent in the payment market. Moreover, it wants to build a solid alternative to the US dollar so as to establish the Renminbi in international financial markets and to circumvent sanctions. Consequently, a clear action plan has already been developed. On the contrary, for the Federal Reserve there is no need to be in a hurry: today, the dollar is widely used across the globe because of the depth and liquidity of US financial market, the size and openness of the US economy as well as international trust in US institutions. It also serves as the world's reserve currency. It is true that if new CBDCs were more attractive than existing forms of the US dollar then the global use of the dollar could decrease but it does not seem an imminent threat. Therefore, discussions are still ongoing between the diverse set of stakeholders. On the other side of the Atlantic, the ECB is studying the specific design features of a digital euro in order to preserve the role of public money as the anchor of the payments systems in the digital age and to contribute to Europes strategic autonomy and economic efficiency. Thanks to the investigation phase carried out between October 2021 and October 2023, the Eurosystem has collected the best alternatives to design a strong digital payment system.
We now see in more detail the different proposals.

Eurosystem

The ECB and the Euro area national central banks launched the investigation phase of the digital euro project in October 2021. The investigation phase, ended in October 2023, aims to address key issues regarding design and distribution. At the end of the investigation phase, the Governing Council could decide to start a realization phase to develop and test technical solutions and business arrangements for a digital euro.

The ECB's aim is to built a digital euro exploit-

ing the strengths of both the Eurosystem and private-sector entities to satisfy user needs in a fast-changing payments landscape.
The Eurosystem has carefully considered how to design the **transfer mechanism** used to validate and verify transactions. The options are illustrated in table 19.

The digital euro will remain a liability on the balance sheet of the Eurosystem, therefore it is important for the latter to retain **full control over the issuance and the settlement**, including the recording and associated verification tasks. For an offline peer-to-peer validated digital euro, settlement in a local storage device would be a suitable solution. This would require installing secure elements in users hardware devices in order to verify and record the transactions, since it would be impossible to contact a third party and request the offline verification. The Eurosystem has not yet taken a decision on the technology that would be best suited for a digital euro; it will choose between either traditional technology, distributed ledger technology or a combination of both for settlement activities.
Supervised intermediaries would be responsible for all end user facing roles in the digital euro ecosystem, being the direct counterparts for individuals, merchants and businesses. Their responsibilities would include offering user-facing services, such as opening accounts or wallets, payment instruments and onboarding and offboarding, encompassing Know-Your-Customer and AML checks. They would also provide devices or interfaces to pay with a digital euro in physical stores, online or person-to-person. More in general, the intermediaries should be responsible also for the distribution of the digital euro if they have the capacity to offer digital euro accounts and payment services and provide front-end solutions; are subject to anti-money laundering/countering the finance of terrorism controls and sanctions regulation-related framework; are solvent under the relevant insolvency law, demonstrate operational readiness and risk control; and are licensed and authorized by an appropriate competent authority and compliant with all applicable legislation [14]. For more detail regarding the European solution for the distribution model, it can be interesting to read also chapter 3.

The Eurosystem would like to configurate two different ways to access the digital euro. The goal is to benefit end users by offering them greater choice. In the specific:

1. **Integrated approach**: accessing digital euro through the already existing PSPs online banking/payment apps. In this way, intermediaries would retain the ability to build their own integrated solution and would attract customers through value-added services, depending on their specific business model.
2. **Harmonized entry point approach**: accessing digital euro through a standardized digital euro app provided by the Eurosystem with a homogeneous look. This will help different parties. For example, this solution can guarantee a faster digital euro adoption for new smaller intermediaries which would not be able to compete with the already existing ones. Moreover, being homogenous across European countries, this app could improve financial inclusion because it can be designated by the Eurosystem in order to be inclusive and accessible to people with low digital and financial skills and resources, as well as people with disabilities and the elderly.

Another detail is discussed by the Eurosystem: the so-called **form factor**. With form factor, we intent the technological tool that enables payer and payee to interact and exchange payment details. For in-store payments (point-of-sale use case), the choice falls to *QR-code* and *NFC contactless payments*. Both have advantages and disadvantages: QR code-based payments could be more easily deployed than near-field communication (NFC) technology as QR codes entail fewer complexities in terms of standards and certification processes. Moreover, there are no dependencies on mobile device manufacturers, ensuring accessibility regardless of device type, which is not the case for NFC. QR codes would also foster a new European infrastructure, contributing to the overall resilience of European payments. On the other hand, NFC technology provides a highly convenient user experience with consumers in the euro area already familiar with. Furthermore, NFC is the only widespread technology which could facilitate the development of a convenient offline payment method by introducing a physical card for the digital euro. Finally, for individuals cases, they could use *contactless technology*, *QR codes* or an *alias/proxy* when making person-to-person (P2P) payments. With regard to e-commerce payments, both a QR code and an alias/proxy functionality would be available.

China

The design of E-CNY follows the concept of safe and inclusive, innovative and user-friendly, and time-evolving.

The E-CNY payment system is already operating in different forms, with both online and offline solutions. In order to preserve users privacy, and thus increasing the presence of the digital Renmimbi in national and in future international financial markets, the PBOC has structured its payment system to collect less transaction information than traditional electronic payments and to not provide information to third parties or other government agencies unless stipulated otherwise in laws and regulations. As consequence, to increase E-CNY's resemblance to cash, the PBOC invented a system called **loosely coupled account links**, shifting the focus on E-CNY

TRANSFER MECHANISM DESIGN	
Online third-party validated solutions	transactions would be made online and would be validated by a third party. There can be multiple advantages with this solution: first of all, transparency of transaction data will be ensured to intermediaries for ALM/CTF purposes. Secondly, it leaves room for flexibility in other design decisions related to the digital euro. However, it will be important to further investigate solutions to increase its resilience to connectivity outages.
Offline peer-to-peer validated solutions	the privacy of low-value proximity payments is guaranteed within limits set by legislation. The time of market implementation for this solution is more uncertain because of its dependence on technological innovation, regulatory changes and security risk tolerance.
Potential peer-to-peer validated solution for online payments with no third party	It is the more experimental options, it will allow remote payments but transactions cannot be checked ex-ante.

FIGURE 19: Hypotheses of transfer mechanism design used to verify transactions by the Eurosystem - Source [13]

wallets rather than bank accounts. Indeed, unlike traditional payments which require transactions to happen between two bank accounts, this system allows transactions to happen between two E-CNY wallets instead, and the latter could not necessarily be associated with a bank account. For this reason, it was possible to introduce the feature of offline payments.
Because of its loosely coupled nature, E-CNY can achieve **manageable anonymity** due to the offline nature which eliminates many of the transaction details normally exchanged in the banking system. Here, for anonymity it is intended that transactions are anonymous vis-à-vis third party intermediaries, such as commercial banks and internet platforms, but the PBOC and other authorized entities can see them. For this reason, the anonymity is manageable since it is the PBOC to design if increasing or decreasing the level and can also take action by deactivating a wallet or reversing a transaction if suspicious or illegal activities are identified.

The distribution of E-CNY follows the traditional currency distribution model: a **two tier system** with two distinct layers of functionality. On the first layer, the PBOC will issue and redeem E-CNY to commercial banks and other authorized entities, such as existing mobile payment platforms (Alipay and WeChat Pay) and telecommunication companies. PBOC tasks include being responsible for issuance and disposal of the digital currency and managing the wallet ecosystem. This allows the E-CNY to be legal tender; therefore, to implement this management structure, the People's Bank of China Law has been revised extending the legal tender of the physical Renmimbi also to its digital form, as expressed in the **article 19**, and highlighting the exclusivity of the PBOC to issue the Renmimbi, expressed in the **article 20**. On the second layer, there are commercial banks and other authorized entities, in charge of distributing E-CNY to the general public. Specifically, under the quota management of the PBOC, the authorized operators jointly provide E-CNY circulation services and retail management, including innovation on payment product design, system development, scenario expansion, marketing, business processing as well as operation and maintenance. Commercial banks are the ones users must reach out to receive E-CNY through a digital wallet and, in this way, PBOC avoid disintermediation in the Chinese financial system. In this way, it also reduces its responsibilities and risk exposure. E-CNY are collected and exchanged through **apps on mobile devices**, jointly developed and shared by authorized operators. Based on the strength of customer personal information identification, the offered wallet solutions in these apps could change. In order to meet the needs of different groups of people, PBOC has designed two solutions: on one hand, a software wallet provides services through mobile payment apps, software development kit (SDK) and application programming interface (API). On the other hand, a hardware wallet uses security chips and other technologies to enable the functions of the E-CNY. Chips are supported by IC card, mobile phones, wearable objects, and the Internet of Things devices, granting the availability of the digital currency.

United States

The Federal Reserve is considering how a CBDC might fit into the US money and payment landscape. And will continue to explore a wide range of design options for a CBDC. One example can be found in the exploratory research known as Project Hamilton carried out by the

Federal Reserve Bank of Boston (Boston Fed) and the Massachusetts Institute of Technologys Digital Currency Initiative (MIT DCI). But this is only one of the leading exploration on the theme.

While no decisions have been made on whether to pursue a CBDC, the analysis suggests that a potential US CBDC would serve the needs of the United States by being **privacy-protected, intermediated, widely transferable and identity-verified**. From the point of view of designing the infrastructure, some assumptions can be drawn: since the Federal Reserve Act does not authorize direct Federal Reserve accounts for individuals, the **intermediate model**, such as in China and in Europe, is the most likely. Under this model, the private sector, especially commercial banks and regulated non-bank financial service providers, would offer accounts or digital wallets to facilitate the management of CBDC holdings and payments, while the Federal Reserves will remain the one issuing the CBDC; as usual, the CBDC itself would be a liability of the Federal Reserve. An intermediated model would facilitate the use of the private sectors existing privacy and identity-management framework, leverage the private sectors ability to innovate and reduce the prospects for destabilizing disruptions to the well-functioning US financial system.

Currently, some steps are taken towards the final project realization. In the specific, there is a public discussion between the Federal Reserve and stakeholders on the main design options [7]. The main findings are reported.
Commenters offer a range of views on **what types of firms** should serve as intermediaries in a potential CBDC system and what the role and regulatory structure for these intermediaries should be. The main conclusions can be summarized in:

- from the point of view of the most representing financial institutions and consumer groups, only currently regulated financial institutions have the experience and supervision necessary to provide this function safely. They also warn about the hypothesis where significant costs would be put on intermediaries without proper consumer protections, because this could attract intermediaries with ulterior motives, such as profiting off user data.
- on the other hand, however, technology companies and payment service providers support using a variety of firms such as nonbank financial service providers and financial technology businesses in order to promote competition and innovation, offering different services with the goal of reaching all the segments in the population.
- Finally, some financial institutions and consumer groups suggest following the guidelines for access to Federal Reserve master accounts to determine eligibility and supervision requirements for intermediaries.

For what concern **offering an offline option**, all commenters across segments support an offline payments option, since this feature can support operational resilience and increase financial inclusion. But there are different views about the priority to give to this topic; the slow down of this design option derives from concerns about potential fraudulent or illicit payments. Technology companies are more ready to accommodate the request for offline payments, because they can offer solutions including Bluetooth or near-field communication technology, offline counters that allow spending up to a certain threshold, and segregated accounts specifically for offline use.

Commenters express a range of views on how CBDC could be interoperable within existing systems:

- Some representing technology companies suggest that a CBDC could act as a *"base layer"* that could be connected to existing payment networks and leverage mobile wallet technology, which could increase adoption and lower costs of implementation.
- Academics, trade associations and technology and payment companies have identified the need for new technical standards.
- Some card networks support adoption of international standards and warn against adoption of unique standards and specifications that could be costly and inhibit interoperability and competition.
- Finally, some merchants and financial institutions highlight the potential high cost of modifying existing payment systems to achieve interoperability.

Comparisons and Final Remarks

Even with some differences, **the intermediated model seems to be the favorite in all the three economies**. Clearly, the financial system is strongly linked to financial institutions therefore building a new payment system excluding them would be detrimental. Including new actors other than banks seems to be preferable in China and, potentially, also in the US: this strategy allows to exploit their market, knowledge and technology leading them back under the supervision of the central bank. For now, only the PBOC is actively involving mobile payment platforms but we cannot rule out the hypothesis that also the Federal Reserve will interact with the big tech companies. In Europe, financial markets rely essentially on banks, for this reason the Eurosystem mainly addresses its attention to this category of intermediaries. **One big difference is the Chinese option of loosely coupled account links**. The possibility of transaction between two E-CNY wallets not

TYPE	Eurosystem	China	U.S
Transfer mechanism (Online vs Offline)	• "Online third-party validated solution" • "Offline peer-to-peer validated solution" • "Online peer-to-peer validated solution" (ex ante)	• Online and offline • Loosely coupled account links • Manageable anonymity	TBD
CB and intermediaries' roles	• Eurosystem: issuance and settlement • Supervised intermediaries: all end user facing roles	• PBOC is responsible for issuance and disposal, inter-institution connects and wallet ecosystem management. It selects commercial banks with certain strength in capital and technology • Authorized operators: provide services for E-CNY circulation	Intermediate model: the private sector would offer accounts or digital wallets to facilitate the management of CBDC holding and payments
Access to digital currency	• Integrated approach: PSP's existing online banking/payment apps • Harmonized entry point approach: new digital euro app	Authorized operators jointly develop and share apps on mobile devices	TBD
Form factor	QR-code, NFC contactless payments, alias/proxy functionality		TBD

FIGURE 20: Comparison between digital economies

associated to any bank account represents a novelty: the ultimate goal is to reproduce as much as possible cash features. This choice is linked to the PBOC's attempt to guarantee a higher level of privacy; recall that China is still recovering from the pandemic, intrusive public health policies and an uptick in government surveillance, thus, PBOC is particularly concerned about this topic. Finally, **the last important difference related to the payment system is how to design access to digital currency**. Indeed, the Eurosystem would exploit the already existing banking or payment apps to smooth changes in currency uses but it would grant also a general Euro app to pursue its goal of harmonization. The PBOC on the contrary will opt for a jointly developed and shared apps, created ad hoc for E-CNY wallets. A summary is reported in table 20.

Risks and New Threats

Technological, Operative and Cyber-Security Risks

Introducing a CBDC could entail dealing with new technologies, new critical operations, new infrastructure and, therefore, also new security and operational risks. Indeed, from the point of view of an attacker the reward could be high, in the specific as the negative consequences for central banks. Central banks and other actors in a CBDC ecosystem will need to face up to this increasingly complex cyber threat landscape as the risks can arrive from different sources: unpredictable threat actors, new types of threats, a large attack surface and points of failure, as well as supply chain risks. A breach of a CBDC system due to cyber-attacks or technical failures could erode confidence at different levels, implying loosing trust in the central bank, in the CBDC system and potentially in all the financial system. A range of reputational, operational and potentially legal impacts must be taken into account by central banks, which should have a clear plan on how to deal with all the different risks; it is important to acknowledge that the entire financial ecosystem is only as strong as its weakest link.
For this reason, all the financial actors must be involved in order to create a network of shared knowledge and communications around problems and solutions. Moreover, new capabilities and new tools are required together with new talents with the function of designing, implementing and operating a secure and resilient CBDC systems. From the point of view of technologies, a CBDC system would most likely leverage a range of solutions that have not been previously used or may be in limited use in a central bank; just to give an example, in recent years **quantum computing** has seen advancement and will play a key role in upgrading cryptographic algorithm. In fact, as previously reported, cryptographic

TECHNOLOGICAL AND CYBER-SECURITY RISKS	
Distributed denial-of-service (DDoS) attacks	an attacker can use computing resources or a network of compromised computers or IoT devices to launch a massive volume of service requests to a CBDC system or services it relies on. This will exhaust the computing resources in a critical area of the ecosystem and the main consequence is the system overload, failures, timeouts or performance degradation.
Advanced persistent threat (APT) attacks	the attacker enters the victim's system and plants malicious software or creates backdoors; then, he observes network traffic, user and system behavior during a long period of time in order to capture data. The attacker can also install malware or poisoning data. This attack is hard to detect due to the advanced technique in place.
Malware (wiperware, ransomware etc) attacks	Malicious software are plant into the target's computers and networks with the purpose of destroying certain computer services or subtracting information and computing assets hostage for ransom payments.
Social engineering attacks	The aim is to take control of an end user's CBDC account through various techniques: phishing, spear-phishing or baiting, SIM swaps or compromised credentials.
Cryptographic key compromise	A malicious actor could try to obtain the private key for claiming ownership of CBDCs by hacking the computer or device containing the key file, searching through the device's memory for traces of the key, conducting cryptanalysis based on collected data that have been generated using the key, or via side-channel attacks
Compromise of the payment process	Along with the different steps in the payment networks there could be some security gaps which can be found and exploited by the attacker. The result would be the possibility of making a purchase without paying, redirecting payments to a different recipient, replaying payment instructions, or harvest payments from wallets that do not require payer consent.
Malicious end user attacks	It cannot be excluded that end users may have some interest in defrauding their own CBDC payment device or mobile application with the intent to counterfeit CBDCs or double-spending it.
Insider sabotage attacks	with or without attention, an employee or someone who has access to a CBDC system can exploit its position to cause the malfunctioning of the system by damaging the hardware, deleting key information, shutting down services, providing incorrect input or enabling other threat actors.
Insider fraud	a financial fraud carried out by a malicious insider who leverages their privileged access.

FIGURE 21: Technological and Cyber-Security Risks

algorithms represent a considerable weakness of the system, since a threat actor can have different ways to attack and breach the system. Quantum computing will help CBDC to realize a more *crypto-agile system* so that upgrades follow the same pace of new attacks.
In table 21, we explain the main technological and cyber-security risks which could compromise the confidentiality, integrity or availability of a CBDC system. This list can be a good starting point to get an overview, but it is not to be considered exhaustive.

Another important point is dealing with **operational threats**. Once again resilience must be ensured against sophisticated methods and tactics perpetrated by bad actors. A main threat is represented by **technology failures**, like software or hardware bugs, failed storage media, software patched or upgrades not fully tested; of course, the more complex the technology is the higher the probability to encounter this type of threat. The main consequence is the disruption of the CBDC system which can open the doors to other cyber-security attacks. Moreover, part of these failures can be reconducted to the phenomenon of **technology obsolescence**: if it is no longer possible to update the technology, could be because venders may withdraw support or security patches or bug fixes are no longer available, then the system cannot be well protected against the continuous evolving attacks. In this way, not only operational, but also reputational and legal risks become a real concern for central banks.

Privacy Risks

Another big concern raised by the introduction of a CBDC in the financial system is the risk associated to **privacy and data collection**. With this new financial architecture, new actors are accessing personal data, for example big techs; for this reason regulations restricting the types of data that could be collected would be necessary.
In the current system, banks and credit companies have the greatest access to transaction data. This data is then used primarily to score users on their creditworthiness, which permits lending institutions to decide the rates at which they will lend to each individual. As payments go digital, private companies are increasingly monetizing payment data with an increasing trend. Thanks to their control of social media, of the online marketplaces and mobile technologies, the global tech giants could use such users data to reduce the information asymmetry that lies at the heart of financial intermediations. If banks were incapable to monitor transaction data (for example if consumers hold digital currency ex-

clusively), they may be interested in purchasing it, increasing their funding costs. Consequently, data-driven models could jeopardize privacy and pose the risk of personal information being misused. Moreover, in Europe, the expansion of big tech companies could make us dependent on technologies governed elsewhere. Therefore, the Eurosystem is searching for the right balance between the **trade-off anonimity versus AML/CFT requirements**. It cannot be ruled out that the Eurosystem will guarantee privacy for lower-value payments, with the ability to determine the payee's identity under exceptional circumstances. However, in general **full anonymity is not a viable option for different reasons**: from a public policy perspective, it would raise concerns about the digital currency potentially being used for illicit purposes. In addition, from the financial stability perspective, it can be difficult to limit its use as a form of investment, unless introducing limitations. Anyway, a good starting point is to ensure a level of privacy equal to or higher than that of private digital solutions, otherwise some other private solutions would be preferable by users. Following the PBOC's example, digital euro transaction data are not meant to be visible to the Eurosystem beyond what is strictly needed to perform its functions. Under this set-up, personal and transaction data would only be accessible to intermediaries to ensure compliance with AML/CFT requirements and relevant provisions under EU law. Concerns about regulations being circumvented, including to bypass international sanctions, have become even more prominent recently, notably in relation to crypto-assets. Thus for ALM purposes, users in a CBDC ecosystem can need to be identifiable and this digital identity can be designed to largely automate and facilitate the Customer Due Diligence (CDD) process. The Commission's proposal for a regulation on the digital euro addresses on a legal basis the discussions reported above. The most important discussion is about the data management that every transaction between two users would generate. Distribution and use of a digital euro when personal data is processed shall follow the privacy regulations already issued by the European Commission, such as *Regulation (EU) 2016/679 (GDPR) and Regulation (EU) 2018/1715 (EUDPR)*, which guarantee the fundamental right of protection of natural persons in relation to the processing of personal data. Thus, to be compliant with this, the digital euro regulation includes several articles (34 to 36) about privacy and data protection. For example, **Article 34** sets the cases where Payment Service Providers are allowed to process personal data for both online and offline transactions. Going into more detail, PSPs shall implement appropriate technical and organizational measures to ensure that any data communicated to the European Central Bank and the national central banks or to providers of support services do not directly identify individual digital euro users. Similarly, **Article 35** defines the tasks for which the ECB and national central banks may process personal data, which includes the settlement of digital euro payment transactions. Thus, the processing of personal data is required only for the tasks related to the distribution and use of the digital euro laid down in the mentioned articles as well as for existing tasks carried out in the public interest or for compliance with a legal obligation established in Union law as defined in *Directive (EU) 2015/2366*. Such tasks include the prevention and detection of fraud, combating money laundering and terrorist financing, the fulfilment of obligations related to taxation and tax avoidance, and the management of operational and security risks. The Commission declares that processing activities respect the requirements of Union data protection law by establishing the respective responsibilities of a controller from a data protection perspective, notably that of the European Central Bank and national central banks and PSPs. Where the European Central Bank and national central banks determine the means of processing as a controller, state-of-the-art security and privacy-preserving measures will ensure that personal data is pseudonymized or encrypted in a manner where personal data processed cannot be directly attributed to an identified or identifiable digital euro user. Finally, the procedure to verify whether any of PSPs customers are designated persons or entities subject to EU sanctions is developed to ensures that any personal data to carry out such verifications are adequate, relevant, and limited to what is necessary.

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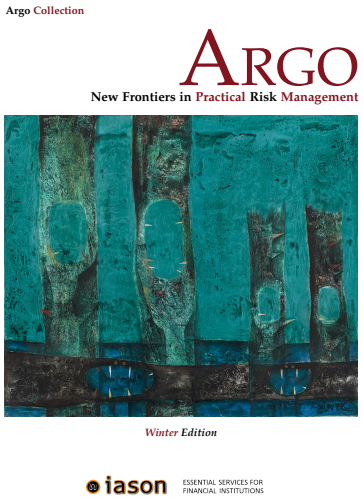

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