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ORIGINAL PAPER

The potential impact of a central bank digital currency (CBDC) on the banking sector: the case of a digital euro

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Abstract
The introduction of central bank digital currencies (CBDCs) has attracted growing interest from academic research, central banks and political decision-makers. Most of the existing literature is focused on the impact of a CBDC on monetary policy and financial stability. The potential impact of a CBDC on the profitability and resilience of the respective banking sector has hardly been discussed so far. However, fees from payment transaction services could decline to the extent that transactions in a CBDC would substitute other electronic payment instruments for which banks charge fees. In addition, refinancing costs could increase if comparatively cheap financing from retail deposits has to be replaced by other, more expensive, financing instruments. This paper presents a model which allows for estimating the potential negative impact of a CBDC on the banking sector by simulating the loss of transaction fees and the increase of financing costs for alternative substitution rates and funding spreads. Furthermore, we apply our model to the potential introduction of a digital Euro based on current market data. The analysis demonstrates that the annual fee losses could be up to €4.2 billion. The associated refinancing need due to replacements of deposits by digital euro holdings could be up to €650 billion. Therefore, a compensation model for banks and payment service providers is needed to avoid adverse consequences from introducing a CBDC.

Keywords Central bank digital currency (CBDC) · Digital euro · Payment services

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1 Introduction

The introduction of a central bank digital currency (CBDC) has attracted growing interest from academic research, central banks and political decision-makers. An important driver has been progress in distributed ledger technology (DLT) and the tokenisation of assets, rights and payment instruments, which enables the digital encryption of financial instruments ("crypto assets") (e.g. Lavayssière and Zhang, 2024; Arslanian, 2022; Gryglewicz et al., 2021; Sunyaev, 2021; Lo et al., 2020; Kim et al., 2018; Lipton, 2018). These include payment tokens (cryptocurrencies), which are primarily used to process payments in a decentralised peer-to-peer network. Tokens can also contain smart contracts that are automatically executed when certain events occur (e.g. Khan et al., 2021; Cong et al., 2019; Corrales et al., 2019). Additionally, so-called "stablecoins" have been introduced. Their market value is linked to an external reference such a fiat currency like the U.S. dollar, a commodity such as gold, or other crypto assets (e.g. Hoang et al., 2021; Lennart et al., 2021; BIS, 2019). Due to the ongoing digitisation both of the financial and the "real" sector, changes in payment behaviour including declining cash usage in day-to-day payments many central banks are analysing the potential benefits and risks of a CBDC.

China has been working for more than ten years on a digital renminbi ("digital RMB" or "e-CNY") (Bhattacharya, 2022; Broby, 2024). The introduction of a digital euro is expected to be decided upon by the end of 2025 (ECB, 2024a). Similar projects are being carried out in other countries: a digital pound (Bank of England, 2023; Bank of England, 2020), a digital US dollar (Federal Reserve, 2023), a digital yen (Bank of Japan, 2024; Bank of Japan, 2020), an e-krona in Sweden (Sveriges Riksbank, 2024; Sveriges Riksbank, 2017), along with emerging economies like Nigeria, which became the first African country to introduce a CBDC (eNaira) (Ree, 2023). However, so far only the Bahamas introduced a fully operational CBDC in 2020, the so-called "Sand Dollar" (Branch et al., 2023). A profound understanding of the impact of a CBDC and its manifold design options on monetary policy and financial stability is essential to avoid unintended consequences and mitigate inherent risks.

Most of the existing literature is focused on the impact of a CBDC on monetary policy and financial stability (e.g. Prodan et al., 2024; Vollmar et al., 2024; Kosse and Mattei, 2022; Minesso et al., 2022; Kumhof et al., 2021; Carapella et al., 2020; Brunnermeier et al., 2019a; Brunnermeier et al., 2019b, Bindseil, 2019). Depending on the characteristics of a CBDC, the transmission of monetary policy measures could be affected. An important aspect relates to the question of whether or not a CBDC should bear interest (e.g. BIS, 2020; BIS, 2018; Davoodalhosseini, 2020; ECB, 2020). If the primary objective is to offer a digital alternative to physical cash, the answer should be negative. On the other hand, an interest-bearing CBDC could pass on policy rate changes immediately to CBDC holders, which could also generate incentives for commercial banks to adjust their rates more quickly. Other aspects of a CBDC include the technical possibility to allow for a "programmable monetary policy" (e.g. money transfers that have an "expiration date" or are conditional on being spent on certain goods) (BIS, 2020; George et al., 2023). There is also some research on the interdependencies between an interest-bearing CBDC and bank lending activities (e.g. Chiu et al., 2020; Andolfatto, 2018).

It is argued that a CBDC could increase the risk of bank runs, if retail customers could easily switch to a safe asset like a CBDC (e.g. Ahnert et al., 2022; BIS, 2020; Vives, 2019). Depending on the exact features and the quantitative availability, a CBDC could facilitate the switch from bank deposits into central bank money and thus increase the speed and scale of these flows. Such developments could exacerbate threats to financial stability, including a restricted credit supply (BIS, 2018). Nevertheless, these risks could be mitigated, e.g. by imposing quantitative limits on individual CBDC deposits and designing the CBDC as a more “cash-like” and less “deposit-like” payment instrument (e.g. Ahnert et al., 2024; Bindseil, 2020; Panetta, 2018). However, the potential implications of a CBDC on the profitability and resilience of the respective banking sector have hardly been discussed so far. A recent paper (Bellia et al., 2025) estimates the potential impact of a digital euro on the sensitivity of banks’ profitability resulting from the partial replacement of deposit-based funding. However, it does not account for the negative effect of a digital euro on banks’ payment-fee income. In our simulation model, we estimate the combined impact of higher funding costs and reduced payment-fee revenue under different scenarios. Nevertheless, we view both approaches as complementary, helping to develop a more comprehensive understanding of this important issue.

2 Research question and related research

Transaction services, i.e. the execution of payments and securities transactions, are an important pillar of the business model of many banks. The introduction of a CBDC raises the question about the role of banks and other payment services providers (PSP) like e.g. (credit) card organisations in the process of issuing, distributing and executing payments in a CBDC. Depending on the architecture of a CBDC their role in the payment industry could be negatively affected, if basic services for a CBDC would have to be offered free of charge to end customers and to the extent that transactions in a CBDC would substitute other electronic payment instruments for which banks charge transaction fees. In addition, refinancing costs could increase if comparatively cheap financing from retail deposits has to be replaced by other, more expensive, financing instruments. Hence, a CBDC could intensify the disintermediation of banks and other deposit takers with potentially negative implications for the profitability of the banking sector. The level of acceptance and the potential adoption path of the respective CBDC determine the size and the development of such an impact over time.

This paper presents a model which allows for estimating the potential negative impact of a CBDC on the banking sector by simulating the loss of transaction fees and the increase of financing costs for alternative substitution rates and funding spreads. Furthermore, we apply our model to the potential introduction of a digital euro. There are basically two reasons for chosing the digital euro as a case study. Firstly, the digital euro has reached a very advanced state in the preparation phase. Secondly, the availability of granular data on payment instruments and behaviour, fees and funding spreads provides a reasonable foundation for our data analysis. Our analysis for the case of a digital euro shows that annual fee losses could be in the range of €2.1 billion to €4.2 billion. The associated refinancing need, due to the replacement of deposits with digital euro holdings, could amount to between €324 billion and €650 billion. This would translate into additional refinancing costs of around €6.5 billion to €19.5 billion per year.

Although our findings for the digital euro cannot be transferred one by one on to other CBDC projects due to differences in regulatory frameworks for financial markets and monetary policies, our research provides also insights relevant for other CBDC projects which are currently under consideration.

The paper begins with a brief overview of the obectives and features of a CBDC. Then we present the methodology underlying our simulation model. In the following we apply the model to the case of a digital euro. Finally, we discuss the results and limitations of our work and suggest fields for further research.

3 Objectives and features of central bank digital currencies (CBDCs)

Money acts as a means of payment, a unit of account and a store of value for a currency area. Central bank money (CBM) so far consists of physical cash (notes and coins, NAC) and reserves held by banks and other qualifying financial institutions as central bank deposits. In addition, central banks facilitate the usage of private money, i.e. electronic commercial bank deposits, by allowing commercial banks to settle interbank payments using central bank money and enabling convertibility between commercial and central bank money through the provision of NAC (e.g. BIS, 2003).

A CBDC would be a new type of central bank money (BIS, 2020; BIS, 2018) representing a digital alternative to NAC issued directly by the central bank. As such, it would have the status of legal tender and would not bear interest. Depending on the scope, a CBDC could either be used by the general public ("retail CBDC") or alternatively for interbank payments and securities transactions ("wholesale CBDC") (e.g. BIS, 2018; ECB, 2020). As the current discussion about CBDCs refer to a broadly available, general purpose CBDC that could be used for everyday payments, the concept of a wholesale CBDC will not be discussed in this paper.

A CBDC is supposed to complement, but not replace, physical cash. A major focus of existing CBDC projects is on improving efficiency and facilitating innovation of national and cross-border payment systems in the digital age. Furthermore, a CBDC could enhance protection against money laundering, tax fraud and terrorist financing (e.g. Bank of Canada, 2020; Bank of England, 2020; Bank of Japan; BIS, 2020; Boar et al., 2020; ECB, 2020; Federal Reserve, 2023; Sveriges Riksbank, 2017). Moreover, a CBDC could foster broad access to banking services and therefore support financial inclusion in emerging economies (Lannquist and Tan, 2023). Some promoters of a CBDC maintain that citizens will no longer have access to central bank money if demand for NAC continues to fall and becomes marginalised in the future. In such a scenario, trust in the currency would entirely depend on trust in financial intermediaries issuing commercial money (e.g. Barontini and Holden, 2019; Sveriges Riksbank, 2018).

In order to achieve a high level of acceptance, a CBDC should be convenient to use in day-to-day payment transactions, including point of sale and person-to-person payments, both online and offline. The basic services of a CBDC should be free of charge for end users and require only minimal investment in technology.

4 Methodology

The introduction of a CBDC will have an impact on the volume of monetary aggregates and the distribution of their components. The monetary aggregate M1 is defined as the sum of currency in circulation (NAC) and overnight deposits (D). Central bank money (CBM) consists of NAC and central bank deposits of commercial banks (central bank reserves, CBR). A CBDC, being a digital form of NAC and therefore another form of legal tender, would amend both the definition of M1 (Eq. 1) and central bank money (Eq. 2).

$$M1 = NAC + D + CBDC \tag{1}$$

$$CBM = NAC + CBR + CBDC \tag{2}$$

Hence, the introduction of a CBDC would trigger substitutions between those different monetary components if a CBDC is considered a safe, convenient and fast payment instrument. The basic substitutional relationships between those components are summarised in Table 1. Table 1 distinguishes four types of basic transactions that may be observed upon the introduction of a CBDC. Firstly, a CBDC could partially replace NAC in day-to-day payment behaviour, which itself would be neutral for the monetary aggregates M1 and CBM. It would also have no immediate impact on the profitability or refinancing costs for banks. Secondly, a CBDC could replace deposits, i.e. commercial money, for non-cash transfers of value. As this would require withdrawals from deposits to CBDC wallets, deposit volumes and reserves of banks at the central bank would decrease, presuming that the holders of CBDC have a direct claim on the central bank. Consequently, fees from electronic payments executed by

Table 1 Impact of a CBDC on monetary aggregates and PSPs

	Impact of transaction type							
Transaction type	ΔNAC	ΔCBDC	ΔCBR	ΔD	ΔM1	ΔCBM	Δtrx_income	Δref_costs
NAC/CBDC substitution	↓	↑	→	→	→	→	→	→
D/CBDC substitution	→	↑	↓	↓	→	→	↓	↑
P2P	→	→	→	→	→	→	→	→
POS	→	↑	→	↓	→	→	↓	↑

↑ = increase; ↓ = decrease; → = no change

NAC Notes and coins, D Deposits, CBR Central Bank Reserves, trx_income Fees from payment transactions, ref _costs Refinancing costs

Source Own analysis

banks would drop and bank refinancing costs could increase if the refinancing gap created by declining retail deposits had to be closed by other, usually more expensive, funding instruments (e.g. open market transactions with the central bank). Furthermore, Table 1 shows that P2P transactions using a CBDC would be neutral on the parameters mentioned above. However, if a CBDC is used for online payments or at physical stores, transactions fees for banks and PSPs could be negatively affected, e.g. when replacing direct debit or direct credit payments. In addition, this could also trigger higher refinancing costs. As we leave aside the additional IT costs caused by the impementation of a CBDC, the total costs of a CBDC (*TC*) for the banking sector is the sum of the estimated fee losses (*FE*) and the increased refinancing costs (*FC*) (Eq. 3). These, in turn, depend on the substitution rate for the respective payment instrument (r_i), the underlying payment volume in terms of transaction value (pay_i) or transaction numbers (trx_i), the respective fee rate in percentage points (α_i) and/or in € per unit (β_i) and the incremental refinancing costs in percentage points (c_j) (Eq. 4). Some financial institutions charge a fixed fee per transaction, which may or may not come on top of the volume-based fees. Fees and replacement rates may vary per instrument i. It should be noted that fees in payment services are usually highly regulated and therefore are treated as exogenous in our simulations, whereas financing spreads depend on a variety of factors including liquidity in the money markets and bond markets, central bank rates, inflation expectations and overall economic situation. Due to the lack of empirical data drawn from past evidence of already widely distributed CBDC, our simulation is based on a broad range for possible funding spreads. In our case study of a digital euro we look into historical funding spreads between daily deposit rates and corresponding funding costs from investment grade bonds, swap rates and central bank funding rates. Against this background the estimates from our simulations cover a wider range and need to be treated with utmost caution.

$$TC\left(r_i, c_j\right) = \Delta FE\left(r_i, \alpha_i\right) + \Delta FC\left(r_i, c_j\right) \tag{3}$$

$$\begin{aligned} TC\left(r_i, c_j\right) = &\sum_{i=1}^{n} pay_i \cdot r_i \cdot \alpha_i \\ &+ \sum_{i=1}^{n} trx_i \cdot r_i \cdot \beta_i + \left[\sum_{i=1}^{n} pay_i \cdot r_i\right] \cdot c_j \\ &r_i \in R\ with\ R : [r_{min}; r_{max}] \quad c_j \in C\ with\ C : [c_{min}; c_{max}] \quad i \in [1 \ldots n] \end{aligned} \tag{4}$$

Another important question concerns the adoption path of a CBDC and hence the speed at which the respective substitution rate will be reached. The more convenient and attractive the use of a CBDC is for retail customers, the faster the acceptance and diffusion of the CBDC will be. The cost simulations depend on the assumptions for the substitution rate, the incremental refinancing costs and the adoption period t. The respective trajectory is derived from the implicit compound annual growth rate (CAGR) applicable to the assumed initial value in the first year of adoption to the expected end value after n years (Eqs. 5 and 6).

$$TC\left(r_i, t, c_j\right) = \sum_{i=1}^{n} pay_i \cdot r_{it} \cdot \alpha_i + \sum_{i=1}^{n} trx_i \cdot r_{it} \cdot \beta_i + \sum_{i=1}^{n} pay_i \cdot r_{it} \cdot c_{jt} \tag{5}$$

$$CAGR_{i,n} = \sqrt[n]{\frac{r_{in}}{r_{i0}}} \tag{6}$$

$$r_{i,t} = r_{i0} \cdot \left(1 + CAGR_{in}\right)^t, t \in [1; n] \tag{7}$$

In order to estimate potential fee losses and increased financing costs for the banking sector associated with the introduction of a CBDC, one needs to identify the key parameters of these cost items. The starting point of our analysis marks the existing payment structure in the respective currency area, data on payment fees and the relevant macroeconomic data impacting the size of the overall fee pool of the payment sector. Subsequently, the potential refinancing spreads and substitution rates need to be simulated to estimate fee losses and increased refinancing costs induced by the replacement of existing electronic payment instruments and deposits by the CBDC. Figure 1 illustrates the type of data needed, the corresponding data sources and data flows for the case of a digital euro.

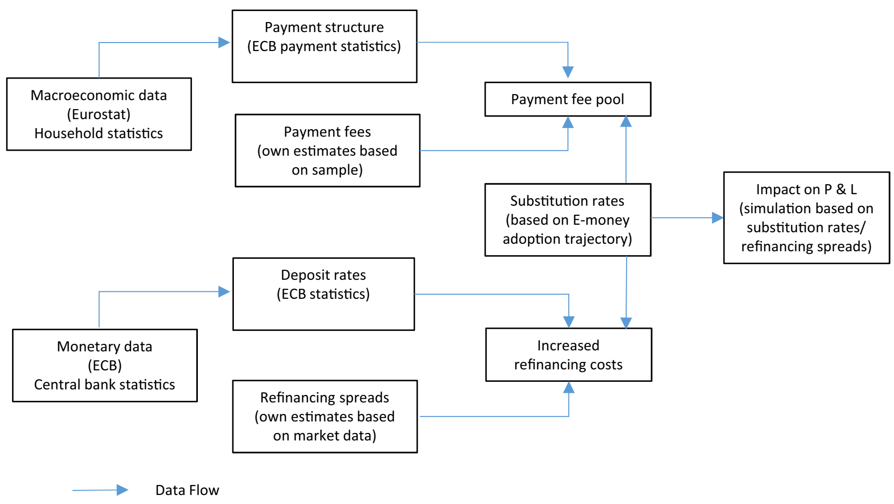

Fig. 1 Data sources and data flow of the simulation model (the case of a digital Euro).

5 The case of a digital euro

Like most of the other CBDCs currently in the preparation phase, a digital euro intends to offer a secure, efficient and trustworthy digital payment alternative in the digital age. The digital euro issued by the ECB is intended to become a digital form of central bank money available to the general public as an alternative to NAC. As such, the digital euro would also have the status of legal tender. Hence, the digital euro shall not replace the use of cash but add to the current spectrum of payment instruments.The introduction of a digital euro has gained momentum since the idea of a CBDC for the eurozone was publicly presented in 2020 (ECB, 2021; ECB, 2020).

In October 2021 the ECB launched an investigation phase by analysing the feasibility of a digital euro, including core design features, technical and legal aspects (e.g. ECB, 2022a; b). This process was accompanied by extensive discussions with market participants and feedback on prototyping exercises from potential users and technical service providers (e.g. ECB, 2023a; b; c). The work of the investigation phase also covered the digital euro compensation model for banks and other PSPs, considerations on digital financial inclusion, and the envisaged rollout approach. At the end of the investigation phase, the results were documented in a draft regulation for the introduction of a digital euro (European Commission, 2023).

In order to protect monetary and financial stability, the current proposal on the design of a digital euro stipulates that holdings of individuals would not be remunerated and would be subject to holding limits. Based on the current design the digital euro would not be programmable but would allow for conditional payments (ECB, 2023a). The privacy and data protection of digital euro users shall be ensured in line with the “privacy by design” concept. This approach makes data protection an essential component of the respective core functionality embedded in IT systems and business practices, e.g. by using cryptographic technologies. All parties involved in the digital euro scheme have to comply with the standards of the European Union Data Protection Regulation (EUDPR) and the General Data Protection Regulation (GDPR). Although data protection is named as a key priority, the Eurosystem has to make sure that market participants comply with EU law and that end-users are protected from fraudulent activities. Therefore, the technical design of a digital euro should improve capabilities to counteract financial crime like tax evasion, terrorist financing and money laundering. Effective fraud detection and prevention is essential to maintain trust in a digital euro as an attractive and safe payment method. Therefore, the system architecture has to carefully balance the individual rights of privacy and data protection with the collective interest to prevent illegal activities.

On 18 October 2023, the Governing Council of the ECB announced it is entering the next phase of the digital euro project—the preparation phase, which started on 1 November 2023 and is scheduled for two years (ECB, 2023d). It will involve finalising the design and features of a digital euro, based on further testing and experimentation to ensure that key requirements and objectives will be met. Another focus will be the further development of the technical platform, the selection of potential service providers and the finalisation of the digital euro rulebook (ECB, 2024a, b). The ECB has been working on a rulebook for a digital euro, which will provide a single set of rules, standards and procedures for usage of a digital euro. Major components

Table 2 Payment statistics (2023) and selected ratios

Payment instrument	No. trx (bn)	No. trx (%, excl. cash)	Value of trx (tn €)	Value of trx (%, excl. cash)	ø ticket size (€)	No. trx (%, incl. cash)	Value of trx (%, incl. cash)
Payment statistics (2023)							
Card payments	76.0	54.9%	3.0	1.4%	39.9	28.4%	1.3%
Credit transfer	29.8	21.5%	206.7	92.8%	6947.9	11.1%	91.7%
Direct debit	21.5	15.5%	10.0	4.5%	467.0	8.0%	4.5%
E-money	8.9	6.4%	0.5	0.2%	56.2	3.3%	0.2%
Other	2.2	1.6%	2.5	1.1%	1113.6	0.8%	1.1%
Total (excl. cash trx)	138.4	100.0%	222.7	100.0%	1609.8	51.7%	98.8%
Cash trx	129.4		2.8		21.6	48.3%	1.2%
Total (incl. cash trx)	267.8		225.5		842.2	100.0%	100.0%

Noters: no. Number of, *trx* Transactions, *cash/cash trx* Cash transactions.

Source ECB, own analysis.

Table 3 Selected macroeconomic data Eurozone (2023)

GDP (m €)	Private consumption (m €)	Private consumption (% GDP)	Population (m)	No. of households (m)
14,499,937	7,721,177	53%	349	158
ø people per household	ø consumption per household (€)	ø consumption per capita (€)	ø savings rate	ø disposable income (per capita, €)
2.2	48,868	22,124	14%	25,725

Source ECB, Eurostat, own analysis.

of the rulebook include the functional and operational model of a digital euro (e.g. end-to-end flows, core requirements for supervised intermediaries, minimum user experience standards), technical scheme requirements (e.g. IT infrastructure, application programming interface implementation, technical standards) and digital euro scheme management rules (e.g. scheme governance, change management processes). Finally, the Governing Council will decide whether or not to move to the next stage, i.e. the possible future issuance and rollout of a digital euro. The rollout of a digital euro would most likely not start before 2028.

6 Simulations

We simulate the potential impact of a digital euro on the European banking sector based on the presented methodology. The starting point of our analysis marks the existing payment structure in the Eurozone including the development of transaction numbers and transaction values per payment instrument (Table 2). Table 3 shows the relevant macroeconomic data, notably the total consumption of private households, the average disposable income per capita, and the corresponding savings rate. These data are important for estimating total payment volumes and numbers per payment instrument as well as the corresponding transaction fees. Table 2 differentiates non-cash payments using cards, credit transfers, direct debit, e-money and others. In 2023 the total value of non-cash payment transactions was around €223 trillion, based on approximately 138.4 billion transactions. Since the ECB does not regularly report the corresponding figures for cash transactions, we have estimated these figures based on previous studies of retail payment habits (ECB, 2022). The number of more than 129 billion cash transactions underscores the important role that NAC continue to play in day-to-day payment behaviour in the eurozone. However, there are significant differences between countries.

In a next step, we estimate the fee pool based on the underlying payment structure and the average fees charged by financial institutions executing the payment process of the respective instrument. As the use of payments and the corresponding fees vary between retail and corporate customers, we estimate the split of payment volumes and values between these groups (Table 4). In the corporate segment, it will be mainly small and medium-sized enterprises (SMEs) using a digital euro. It should be noted that the figures for corporates do not include intra-company payments, which are often consolidated internally by using cash management and treasury solutions and are therefore not subject to fees for individual payments. In addition, a meaningful separation between payments within the eurozone and cross-border payments between the eurozone and third-party countries is not feasible as the required data is not systematically collected. To estimate the number and value of transactions per payment instrument, we use the macroeconomic consumption data as of 2023 and a typical payment structure of private households. The number and average ticket size per payment instrument and household are in line with statistical data from various sources (Deutsche Bundesbank, 2024; Capgemini, 2023; ECB, 2022).

Along with average transaction fees per payment instrument (Table 5), we have estimated the fee potential per payment instrument and in total (Table 6). The respective fee estimates are based on the officially published pricing tables of a sample of about 50 financial services providers (including private banks, cooperative banks, savings banks, credit card companies and other payment service providers) across the euro area. With regard to the allocation of fees between private and SME customers, we first estimated the respective transaction numbers and values for an average private household, then allocated the remaining volumes to the SME segment.

With an estimated fee volume of about €124 billion, the payment services business is an important cornerstone for many financial institutions in the eurozone. According to the latest market research, the expected CAGR of the eurozone payment business is between 6% and 8% p.a. (Capgemini, 2023; OeNB, 2022). Major drivers include the ongoing shift from physical shopping to e-commerce and mobile commerce along with the ongoing adoption of smartphone-based payment solutions (e.g. Apple Pay, Google Pay) and other payment innovations like BNPL offerings, which are gradually replacing traditional cash payments. Cash payments are free of charge, except fees for withdrawals from or payments into accounts, e.g. in a physical bank branch or at an ATM. In line with the current proposal of a digital euro, we assume that basic functions are also free of charge for retail customers.

Table 4 Estimated split of transactions between private households and corporates (SMEs)

Payment statistics (2023)	Payment structure private households								Payment structure corporates (SME)			Total	
Payment instrument	ø ticket size (€)	ø no. trx p.a. per household	ø no. trx p.m. per household	ø trx value p.a. (€)	ø trx value p.m. (€)	Share of trx value	Total trx value (tn €)	Total no. trx (bn)	No. trx SME (bn)	Value of trx SME (tn €)	ø ticket size SME (€)	No. trx (bn)	Value of trx (tn €)
Card payments	20.0	240.0	20.0	4,800	400	9.8%	0.8	37.9	38.1	2.3	59.7	76.0	3.0
Credit transfer	500.0	24.0	2.0	12,000	1,000	24.6%	1.9	3.8	26.0	204.8	7,889.8	29.8	206.7
Direct debit	350.0	60.0	5.0	21,000	1,750	43.0%	3.3	9.5	12.0	6.7	559.2	21.5	10.0
E-money	20.0	48.0	4.0	960	80	2.0%	0.2	7.6	1.3	0.3	264.7	8.9	0.5
Other	0.0	0.0	0.0	0	0	0.0%	0.0	0.0	2.2	2.5	1,113.6	2.2	2.5
Total (excl. cash trx)	104.2	372.0	31.0	38,760	3,230	79.3%	6.1	58.8	79.6	216.6	2,721.9	138.4	222.7
Cash trx	16.8	600.0	50.0	10,108	842	20.7%	1.6	94.8	34.6	1.2	34.7	129.4	2.8
Total (incl. cash trx)	50.3	972.0	81.0	48,868	4,072	100.0%	7.7	153.6	114.2	217.8	1,907.5	267.8	225.5

Notes: no. Number of, *trx* Transactions.

Source: Own analysis.

Whether and to what extent a digital euro will impact the fee pool of the payment services business basically depends on two factors. Firstly, the type of fee-bearing payment instruments the digital euro will replace. Secondly, the level and speed of digital euro adoption. That is to say, faster and higher acceptance of the digital euro, especially by private households and SME corporate customers, would cause a stronger negative impact on the payment fee pool.

Due to the lack of comparable data from introducing a CBDC in other jurisdictions, it is difficult to estimate plausible substitution rates and their development over time. For the purpose of our simulation, the substitution rate is defined as the percentage rate at which existing payment instruments will be replaced by a digital euro. In the following, we assume that a digital euro could partly replace cash transactions, card-based transactions, direct debit and e-money transactions. In addition, we assume that direct credit transactions, mainly used for larger transaction sizes, are not replaced by a digital euro.

The potential substitution rates could differ per instrument and over time. Therefore, a range for a substitution rate underlying our simulations has to be defined. As a starting point, we looked into the current share of e-money payments (e.g. PayPal) and the development of their adoption rate over the last ten years, as e-money is among the most recently established electronic payment instruments.

The current share of e-money in terms of number of transactions is about 6.49% (Fig. 2). The average growth rate of the number of e-money transactions over the last ten years has been about 22% p.a. in the eurozone, though starting from a low level of below 1% of all payment transactions.

Based on the data for the acceptance of e-money, an adoption period for a digital euro of ten years and a potential replacement rate of 5% to 10% to be achieved after ten years appears to be reasonable. But the factual replacement rate will depend on the attractiveness of a digital euro including scope of application, technical features, level of comfort, trust, cost of ownerhsip and promotion measures. A competitive advantage over existing electronic payment instruments lies in its unique scope, comprising both online and offline transactions, as well as the trust retail customers place in the safety of the Eurosystem and its status as legal tender.Therefore, we simulate the costs of a digital euro for a wide range of replacement rates from 2.5% to 20%.

6.1 Deposit replacement and refinancing costs

The second economic impact for banks in the eurozone could be a change in refinancing costs when a digital euro is established. Traditional non-cash payment instruments like card payments, credit transfers, direct debits and e-money are usually linked to payment accounts, i.e. bank deposits, which constitute an important part of commercial bank refinancing. At the end of 2023, bank deposits amounted to approximately €8.8 trillion in the eurozone, of which around €5.1 trillion came from private households (ECB, 2024c). The household deposits to total funding-ratio for large banks subject to the single supervisory mechanism (SSM) has been around 33% over the last five years (ECB, 2024d). Funding based on retail deposits is particularly important for commercial banks with a substantial retail business. To the extent that customers replace not only cash but also deposit-based payments with digital euro

Table 5 Transaction fees

ø fee per trx (€, %)	
Card payments	1.00%
Direct credit (€/trx)	0.5
Direct debit	0.25%
E-money (e.g. paypal)	2.50%
Other	1.00%
Cash trx	0.00%

Notes: trx Transactions, *SME* Small and medium-sized enterprises.

Source: Own analysis, ECB, World Payment Report (2023).

Table 6 Estimated fee pool 2023

Transaction fees (m €)	Private households	Corporates (SME)	Total
Card payments	7584	22,716	30,300
Direct credit	18,960	12,979	31,939
Direct debit	8295	16,805	25,100
E-money	3792	8708	12,500
Other	0	24,500	24,500
Total	38,631	85,708	124,339

Source: Own analysis.

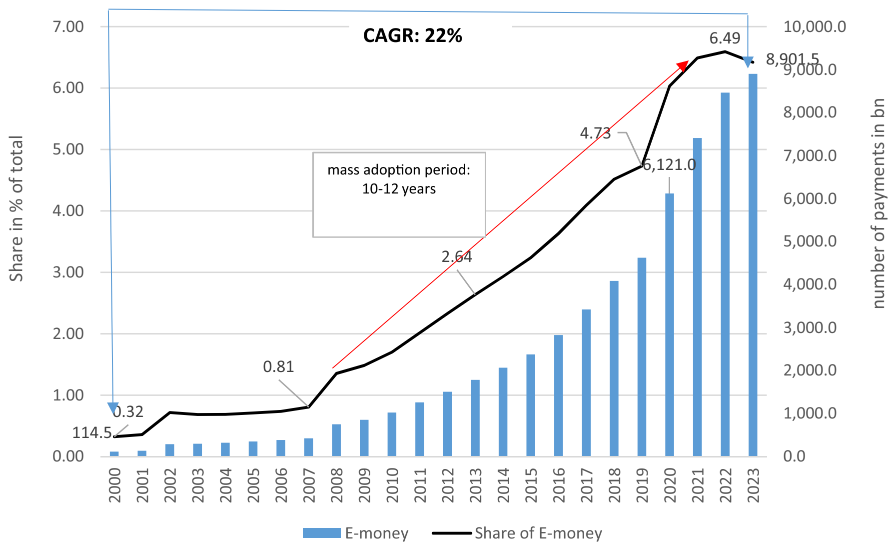

Fig. 2 Development of e-money transactions in absolute terms and share of total in %. Source: Own analysis, ECB data

transactions banks would have to replace the lost deposit volume with alternative funding instruments. These are usually more expensive than comparably low-interest deposits.

For our simulation we assume that banks would replace their reduced deposits either with instruments of wholesale funding (e.g. bonds, medium-term notes, commercial papers), by expanding their refinancing operations with the ECB, other money market instruments or a combination thereof. In either case, refinancing costs will be higher than the interest paid on deposits. Figure 3a and b illustrate the development of funding spreads of medium term and short term financing spreads versus the daily retail deposit rate over the period 1/2023 to 12/2024 in which the interest rate level in the Eurozone has been normalised after an extended period of low to zero interest rates. In Fig. 3a the spreads for a AAA rated 5 year bonds serve as a benchmark. The corresponding figures of a broader investment grade bond portfolio and the 5 year swap rate are moving closely together and reflect funding spreads between 189bp and 327 bp. When looking into the corresponding figures for short term financing (Fig. 3b) spreads fluctuate between 181bp and 388bp when leaving the Main Refinancing Operations rate (MRO) aside as they are usually somewhat more expensive in normal, i.e. non-stressed, money markets. The development of minimum and maximum funding spreads versus retail deposits over the same period indicate average figures of 200 bp and 375 bp (Fig. 3c).

Table 7 gives an overview of minimum, maximum and average funding spreads of different refinancing instruments over the period 1/2023 to 12/2024. The effective increase of funding costs will depend on the the respective spreads, which are quite volatile both between instruments and over time, but also on the individual bank's rating and the chosen refinancing mix. Therefore, we assume a broad range of increased financing costs from 200 bp to 300 bp p.a. to be reasonable, but we calculate our simulations for a much broader range of 75 bp to 325 bp.

In order to get a first indication of the potential loss of transaction fees and increase in financing costs, we apply the lower (200 bp) and higher end (300 bp) of the spreads to the 2.5% replacement scenario. This means that a digital euro could replace, for example, 2.5% of card-based transactions, direct debit and e-money transactions after ten years. We also implicitly assume a 2.5% replacement rate of cash transactions. By definition, however, this has no impact on the fee volume for financial institutions.

Table 8 shows, by way of example, the possible impact of a 2.5% substitution rate on the yearly fee income, which amounts to approximately €1059 million. The refinancing volume could reach around €162 billion, which would lead to increased refinancing costs in the approximate range of €3.2 billion to €4.9 billion p.a., depending on the refinancing cost spreads. Table 8 also displays the estimate of the overall cost for the financial sector in the 2.5% replacement scenario, including reduced transaction fees. The average expected cost would be around €5.1 billion p.a.. We assume that this figure could be reached within a ten-year adoption period, in line with experience from introducing e-money transactions. If the acceptance of a digital euro accelerates faster, the associated fee loss would materialise earlier. It should be noted that these figures do not include the costs for the financial sector due to investments in setting up and operating new IT systems.

6.2 Simulations of transaction fee losses and increased refinancing costs

The above scenario represents a single estimate based on assumptions regarding the substitution rate, fee losses and financing spreads. As these figures are somewhat arbitrary, we conduct a simulation covering a range of substitution rates and a range of incremental financing spreads. We assume that no individual holding limits for digital euros are in place.

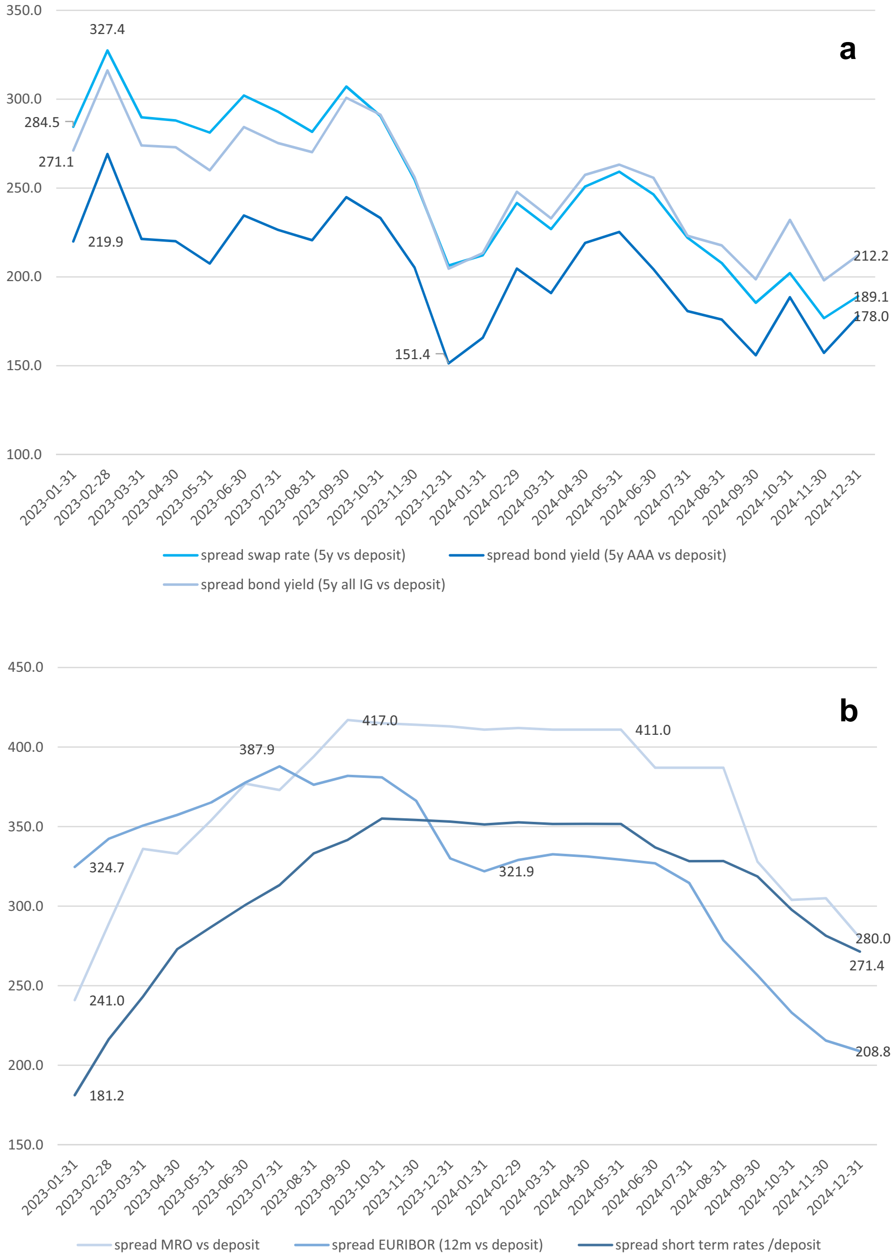

Fig. 3 **a** Funding spreads over retail deposits (in bp) for medium term financing instruments (bonds, 5year swap rate).
b Funding spreads over retail deposits (in bp) for short termn financing instruments (12m Euribor, short term rates, Main Refinancing Operations (MRO)). **c** Development of minimum and maximum funding spreads versus retail deposits 1/2023–12/2024 (in bp). Source: Own analysis, ECB

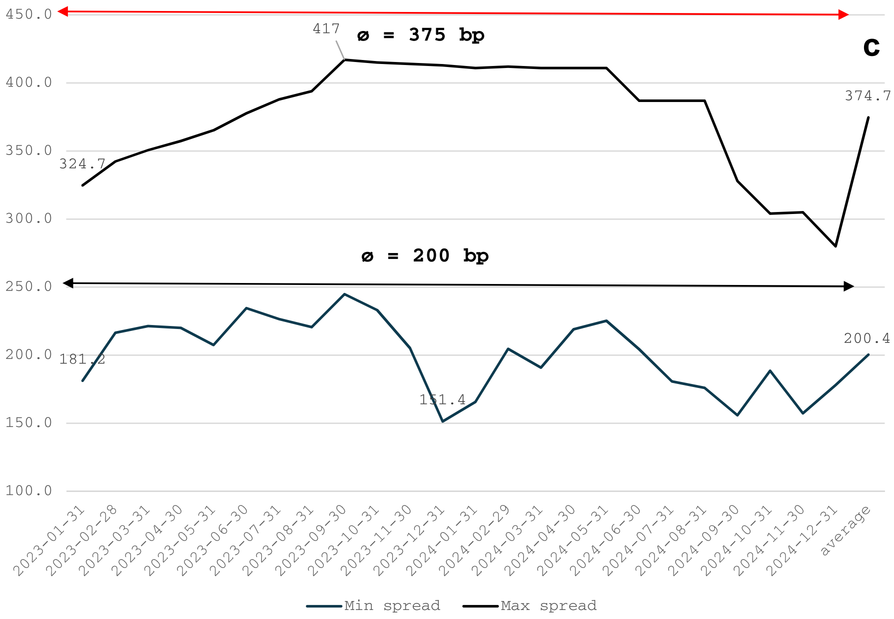

Fig. 3 (continued)

Table 7 Funding spreads above retail overnight deposit rates (1/2023–12/2024)

Refinancing spread	Min (bp)	Max (bp)	Average (bp)
spread MRO vs deposit	241.0	417.0	338.4
spread short term rates/deposit	181.2	355.1	280.5
spread EURIBOR (12m vs deposit)	208.8	387.9	316.9
spread swap rate (5y vs deposit)	176.8	327.4	256.7
spread bond yield (5y AAA vs deposit)	151.4	269.1	204.2
spread bond yield (5y all IG vs deposit)	198.1	316.2	252.3
Average (bp)	192.9	345.5	274.8

Notes: MRO Main refinancing operations, *IG* Investment grade rating.

Source: ECB, S&P, own analysis.

Using Eqs. (3) and (4) and the market data as shows in Tables 2, 3 and 4, we set the simulation intervals as follows:

$$r_i \in R\,with\,R : [0.025; 0.20] \quad c_j \in C\,with\,C : [0.075; 3.25] \quad i \in [1\ldots5]$$

As we consider five different instruments, index i ranges from one to five in our model.

Due to the limited availability of suitable data, simulations need to be based on a wide range and conclusions should be drawn with the utmost caution. In our simulation, we set a range *R* for the replacement rate between 2.5% and 20% that could be reached ten years after adoption. To estimate increased financing costs, we apply a range between 0.75% and 3.25% p.a., which is broader than the estimated range

Table 8 Exemplary scenario for fee losses and financing costs (@ 2.5% substitution rate)

Scenario	Substitution rate	Δ no. trx (m)	Δ value trx (m €)	Δ fees (m €)	Δ refinancing need (m €)	Δ refinaning costs min (m €)	Δ refinancing costs max (m €)	ø Δ refinancing costs (m €)	Total costs min (m €)	Total costs max (m €)	ø total costs (m €)
Cash payments	2.50%	3235.1	69,923.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Card payments	2.50%	1900.0	75,750.0	757.5	75,750.0	1515.0	2272.5	1893.8	2272.5	3030.0	2651.3
Credit transfer	0.00%	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Direct debit	2.50%	237.0	82,950.0	207.4	82,950.0	1659.0	2488.5	2073.8	1866.4	2695.9	2281.1
E-money	2.50%	189.6	3792.0	94.8	3792.0	75.8	113.8	94.8	170.6	208.6	189.6
Total	2.08%	5561.7	232,415.1	1059.7	162,492.0	3249.8	4874.8	4062.3	4309.5	5934.4	5122.0

Notes: no. Number of, *trx* Transactions.

Source: Own analysis.

of funding spreads currently observable in financial markets (Table 7). In order to narrow down the suggested ranges, extensive field experiments with potential users should be made to gain further insights into potential changes in payment behaviour and realistic adoption processes. Figure 4 illustrates the simulation of total costs of introducing a digital euro for different combinations of replacement rates and incremental financing costs, based on the defined ranges R and C. The replacement rates per payment instrument shall be reached at the end of an adoption period of ten years. It is obvious that total costs (fee losses and increased financing costs) increase at a given replacement rate as financing costs rise, and at a given increase in financing costs as replacement rates rise.

Table 9 extracts some data from Fig. 4 to illustrate the overall impact and composition in selected scenarios for the replacement rates 2.5%, 5%, 10% and 20%, combined with average increased financing costs for 100 bp, 200 bp and 300 bp. Depending on the assumptions, annual fee losses could be in the range of around €1.1 billion to €8.5 billion, while increased financing costs are potentially much more relevant, with a corresponding range of €1.6 billion to €39.0 billion p.a.. When assuming a replacement rate of 5% to 10% to be reached 10 years after adoption and an average credit spread over daily retail deposits in the range of 200bp to 300bp, overall costs would be in the range of €8.6 billion to €23.8 billion per year. In all scenarios, fee losses are far less important than increased financing costs. In relation to the overall fee pool in the payment industry, the estimated losses would be around 1.7% to 3.4% of the current market volume for payments in the eurozone (c. €124 billion in 2023).

In terms of refinancing needs, the potential replacement rates of 5% and 10% respectively would translate into a refinancing volume of between €324 billion and €650 billion. This is an extrapolated estimate based on the data provided in Table 8, indicating a refinancing need of around €162 billion in the 2.5% scenario. These figures would correspond to a range of €6.5 billion to €19.5 billion additional financing costs per year. Although the numbers appear high in absolute terms, in relation to approximately €5.1 trillion of private household deposits as of 31/12/2023, these would be equivalent to between 6.3% and 12.6% of the current deposit volume. The results of our simulations are also sensitive to the underlying macroeconomic data (Table 3). Due to the linear structure of our model, a 1% change in GDP would, ceteris paribus, translate into a 1% change in estimated transaction-fee losses and increased refinancing costs. This sensitivity is reflected in the wide range of our simulation results. Another important question concerns the adoption path of a digital euro. Based on the data for the acceptance of e-money, we assume an adoption period for a digital euro of ten years. Figure 5 simulates the possible development of costs for a digital euro for a ten-year period after its introduction. The cost simulations depend on the assumptions for the substitution rate, the incremental refinancing costs and the adoption period t (Eqs. 5, 6, and 7).

In our simplified simulation model, we assume that the refinancing costs are equivalent to the average refinancing spread for the whole period (Eq. 8).

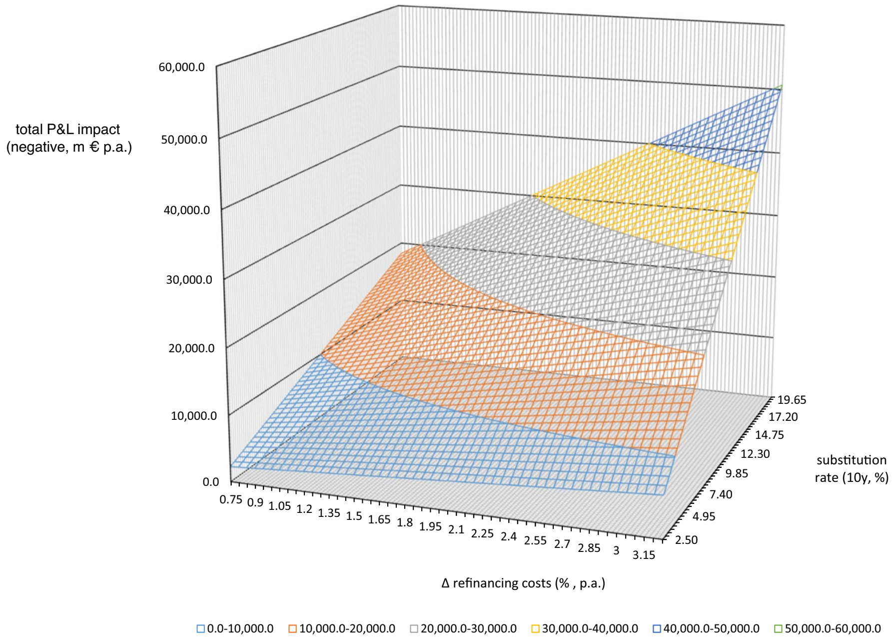

Fig. 4 Simulation of total costs of a digital euro (€ million, ten years after adoption). Source: own analysis

Table 9 Selected scenarios for fee losses and increased financing costs

Scenario	Replacement rate	100 bp		200 bp		300 bp	
1	2.50%	2,685	100%	4,310	100%	5,934	100%
	Δ refinancing costs	1,625	61%	3,250	75%	4,875	82%
	Fee loss	1,060	39%	1,060	25%	1,060	18%
2	5.00%	5,369	100%	8,619	100%	11,869	100%
	Δ refinancing costs	3,250	61%	6,500	75%	9,750	82%
	Fee loss	2,119	39%	2,119	25%	2,119	18%
3	10.00%	10,738	100%	17,238	100%	23,738	100%
	Δ refinancing costs	6,500	61%	12,999	75%	19,499	82%
	Fee loss	4,239	39%	4,239	25%	4,239	18%
4	20.00%	21,477	100%	34,476	100%	47,475	100%
	Δ refinancing costs	12,999	61%	25,999	75%	38,998	82%
	Fee loss	8,477	39%	8,477	25%	8,477	18%

Source: Own analysis.

$$c_{i,t} = c_{i,o} = \left[\frac{c_{min} + c_{max}}{2}\right] \tag{8}$$

$r_i \in [0.025; 0.20]$, $t \in [1; 10]$, $c_j \in [0.075; 3.25]$, $i \in [1 \ldots 5]$, $r_{i,0} = 0.01, \forall i\, n = 10$ $c_{min} = 200bp$ and $c_{max} = 300bp$

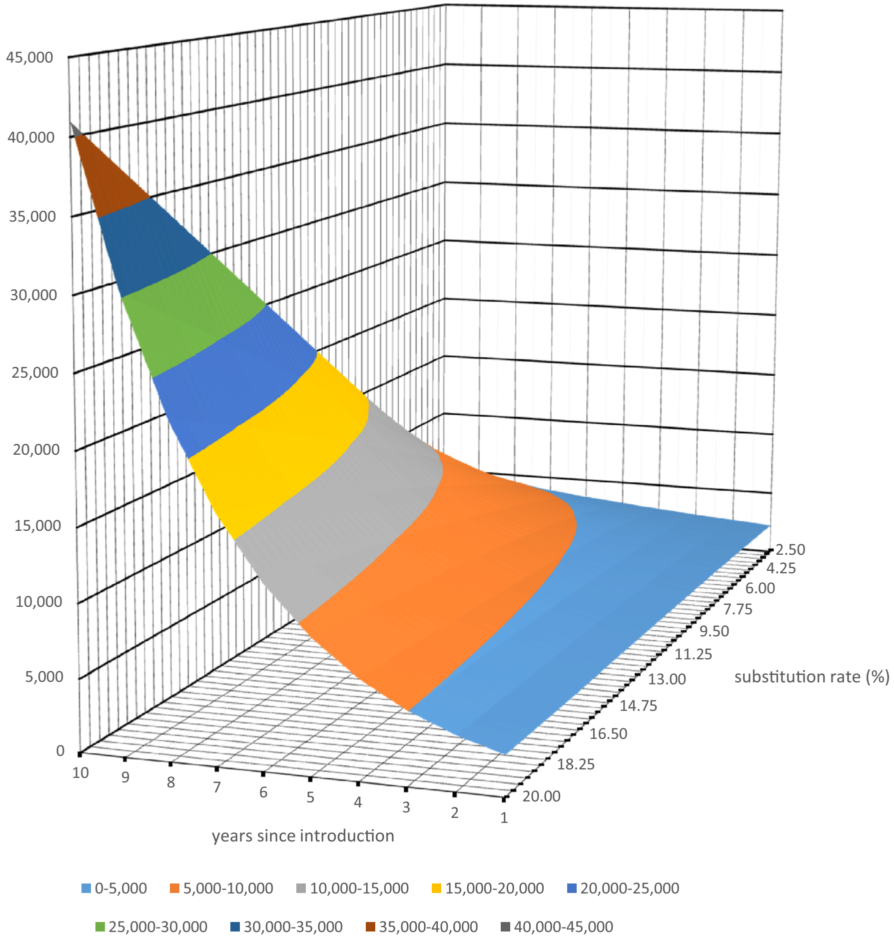

Fig. 5 Simulation of total costs of a digital euro over a ten-year development path (€ million p.a.). Source: own analysis

In Fig. 6 we extract three exemplary adoption paths from Fig. 5 for the underlying substitution rates 2.5%, 5.0% and 10.0%. Based on the numerical assumptions on fees, substitution rates and average incremental refinancing costs, the cumulative costs over the ten-year adoption period could range from about €35 billion (2.5% scenario) to about €90 billion (10% scenario).

It can be concluded that neither the individual components, i.e. the decreasing fee income and the increasing refinancing costs, nor their combined potential impact are of sufficient magnitude to justify serious concerns about introducing a digital euro. However, a reasonable and sustainable profitability of the European banking sector is crucial to financial stability in Europe and beyond. Therefore, the European authorities and the ECB should keep a close eye on a fair and balanced compensation model for banks and other PSPs when eventually introducing a digital euro. Such a model should provide appropriate incentives for marketing and distributing the digital euro

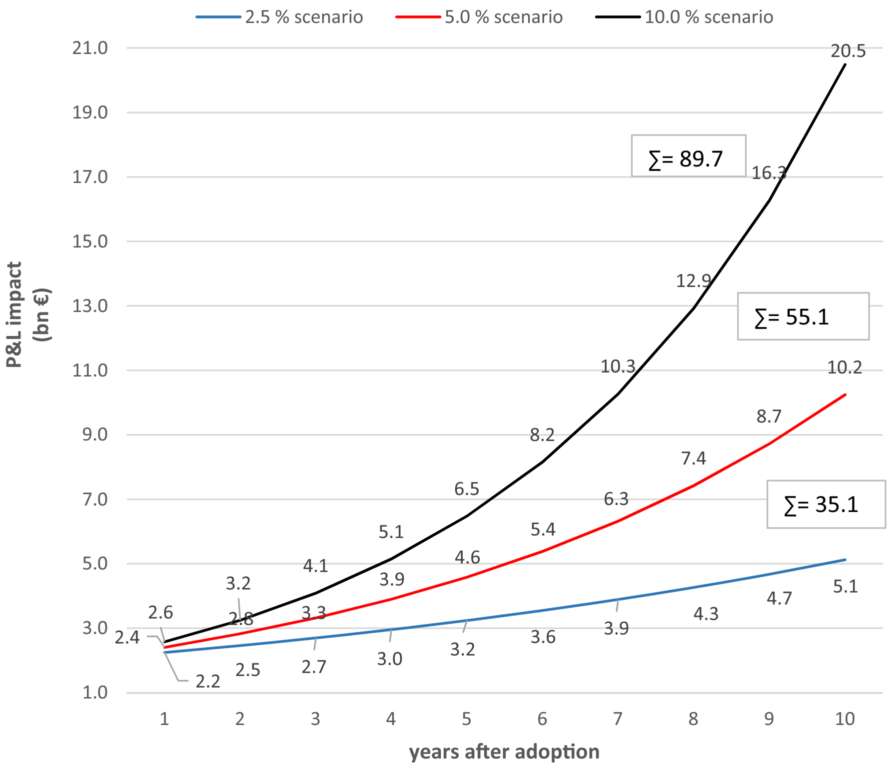

Fig. 6 Negative P&L impact on the European Banking sector in different development scenarios (€ billion p.a.).
Source: own analysis

to ensure broad use by retail customers. Moreover, when the compensation model is designed, it should be calibrated to ensure that the digital euro does not place any additional burden on the banking sector in Europe.

Furthermore, the individual holding limit for a digital euro should be in line with average balances of cash holdings in the eurozone, which need to be quantified closer to a potential launch date. The most recent ECB data showed that the average cash holding per day in the wallet of people in the eurozone was approximately €83 (ECB, 2022). Non-transactional demand for cash as a store of value has been on average around €1270 per person (Zamora- Pérez, 2021).

The results of our simulations suggest that the introduction of a CBDC in general and of a digital euro in particular should be accompanied by a compensation model allowing the financial sector to be compensated their expected fee losses in the payment business. Figure 7 shows the basic transaction flows associated with a CBDC payment in physical outlet or in an e-commerce transaction. Fees could be borne by merchants, users or both. The design of the compensation model will obviously have implications for the efficiency, innovation and inclusiveness of the ecosystem creating the CBDC. In the case of the digital euro no fees shall be charged by financial institutions for basic payment services. However, this may be decided differently

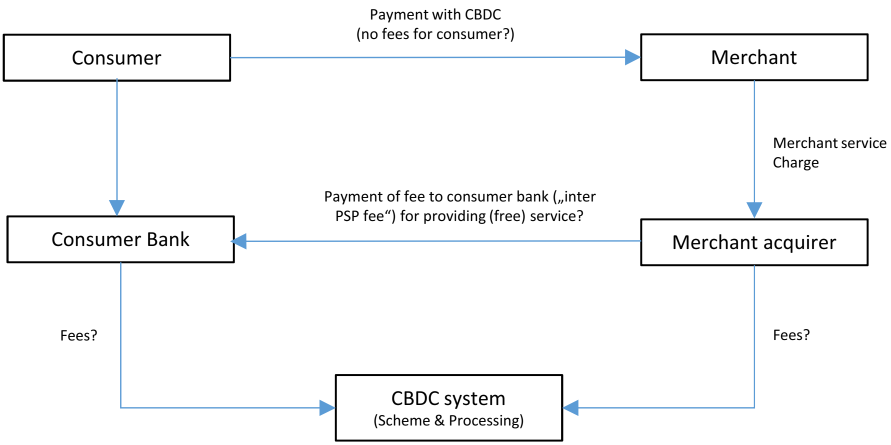

Fig. 7 Basic structure of a compensation model for CBDC services. Source: Own analysis

in other CBDC projects. The calibration of acquiring fees, scheme fees or possibly interchange fees in analogy to the traditional credit card business should be done in a way that upon the introduction of the CBDC is neutral in terms of the profitability of the sector in order to avoid any unintended consequences for the resilience of the financial sector.

7 Conclusions

The introduction of a CBDC could lead to substantial losses of fees in the payments business and increased refinancing costs especially for banks but also other PSP in the respective currency area. On the other hand, commercial benefits from a CBDC could arise from innovative payment solutions. However, these would require a programmable CBDC, which is not currently envisaged for the digital euro (Brühl, 2025).

Our analysis for the case of a digital euro shows that annual fee losses could be in the range of €2.1 billion to €4.2 billion. The associated refinancing need due to replacements of deposits by digital euro holdings could be in the range of €324 billion to €650 billion, translating into additional refinancing costs of around €6.5 billion to €19.5 billion p.a. depending on the level of acceptance by users and the adoption path over time. The impact of a digital euro on the financing costs of commercial banks is much greater than the potential loss of fees in any scenario. However, the results of our simulations do not suggest that the introduction of a digital euro would constitute a potential threat to the stability of the European banking sector.

Our findings for the digital euro cannot be transferred one by one on to other CBDC projects due to differences in regulatory frameworks, monetary policies and payment behaviour. Nevertheless, our research provides the need of a fair compensation model (including individual holding limits) in order to avoid a shock like impact of a CBDC on the profitability and resilience especially of the banking industry. The regulatory framework for a CBDC should be designed in a way that the fees chargeable for CBDC services provided by banks are in line with those applicable for existing electronic payment instruments.

A CBDC would also lead to loss of deposits and increased refinancing costs for banks in other currency areas. The quantitative impact assessment could be conducted with the simulation model proposed in this paper provided that the respective data are available. How banks would respond to increased financing costs depends, among other things, on the macroeconomic situation on the credit markets and the monetary policy of the central bank. Banks could try to pass on their increased refinancing costs to their customers, they could increase the interest rates on their deposits to mitigate the use of a CBDC, or they could employ a combination of these measures. The central bank could also anticipate the impact of the CBDC in its policy, for instance by recalibrating its key interest rates. In order to limit the loss of deposits for the banking sector a CBDC should be non-interest-bearing and subject to individual holding limits that could be fixed in line with average cash holdings close to a possible launch date.

7.1 Limitations and further research

The findings are based on a broad range of substitution rates for a digital euro based on past data for the introduction of E-money instruments. Therefore, it would be beneficial to get a deeper understanding about the potential acceptance of a CBDC like the digital euro in experimental settings with representative user groups. This would allow for a better estimate of the level and speed of diffusion of a CBDC like the digital euro. This would also facilitate the calibration of individual holding caps and fees. Furthermore, our model assumes a linear relationship between fee losses and incremental refinancing costs with substitution rates. Hence, the potential impact of pricing adjustments by banks or PSPs for deposit rates or transaction fees as a response to competitive pressure from a CBDC is not covered by our model and would also be a field for further research.

It should be noted that the introduction of a CBDC would require substantial capital expenditures by the respective central banks and market participants such as banks, PSPs and merchants. In addition, there will be running costs for handling a CBDC, e.g. maintenance of the IT systems needed to handle CBDC transactions and corresponding costs for regulatory compliance. These costs are not part of our model as a reliable cost estimate would require information about the detailed design of the digital euro which is not yet available.

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Data availability The data underlying our analysis are publicly available. No usage of GenAI or similar tools. No external permissions to reproduce material necessary.

Declarations

Conflict of interest The author has no relevant financial or non-financial interests to disclose.

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