EUROPEAN CENTRAL BANK

EUROSYSTEM

Occasional Paper Series

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Central bank digital currency and bank intermediation

Exploring different approaches for assessing the effects of a digital euro on euro area banks

No 293 / May 2022

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Abstract

In July 2021 the Eurosystem decided to launch the investigation phase of the digital euro project, which aims to provide euro area citizens with access to central bank money in an increasingly digitalised world. While a digital euro could offer a wide range of benefits, it could prompt changes in the demand for bank deposits and services from private financial entities (ECB, 2020a), with knock-on consequences for bank lending and resilience. By inducing bank disintermediation, a central bank digital currency, or CBDC, could in principle alter the transmission of monetary policy and impact financial stability. To prevent this risk, options to moderate CBDC take-up are being discussed widely.

In view of the significant degree of uncertainty surrounding the design of a potential digital euro, its demand and the prevailing environment in which it would be introduced, this paper explores a set of analytical exercises that can offer insights into the consequences it could have for bank intermediation in the euro area.

Based on assumptions about the degree of substitution between different forms of money in normal times, several take-up scenarios are calculated to illustrate how the potential demand for a digital euro might shape up. The paper then analyses the mechanisms through which commercial banks and the central bank could react to the introduction of a digital euro. Overall, effects on bank intermediation are found to vary across credit institutions in normal times and to be potentially larger in stressed times. Further, a potential digital euro's capacity to alter system-wide bank run dynamics appears to depend on a few crucial factors, such as CBDC remuneration and usage limits.

JEL codes: E42, E51, G21

Keywords: CBDC, digital euro, bank intermediation, bank runs.

Executive Summary

In July 2021 the Eurosystem announced the launch of a project to explore the case for a digital euro and consider its potential design. Introducing a central bank digital currency in the euro area could offer several benefits, such as allowing general access to central bank money, supporting the Eurosystem's strategic objectives in the payment system and spurring financial innovation. At the same time, a digital euro, if not properly designed, could prompt changes in the demand for bank deposits and services from private financial entities, in turn affecting financial stability and monetary policy transmission. Specifically, lower demand for bank deposits could entail knock-on consequences for banking sector credit provision, risk-taking, profitability and resilience.

The analyses presented in this paper look at how euro area banks' balance sheets and activity might be affected by the adoption of a digital euro. As most decisions regarding the design of a digital euro are still to be taken, a significant degree of uncertainty surrounds the potential demand for it. Moreover, the monetary policy environment in which a digital euro might be introduced could differ from the current one. Acknowledging these uncertainties, this paper proposes a set of analytical exercises that offer insights into the possible implications for bank intermediation in the euro area. To do so, the paper relies on a set of illustrative demand scenarios and distinguishes between normal and stressed times. It also considers possible safeguards to mitigate the potential adverse consequences of introducing a digital euro.

Relying on a number of illustrative scenarios that consider a range of take-ups by the non-financial sector, the analysis in this paper focuses on the implications of digital euro take-up ranging from just under €500 billion to just over €7 trillion. The analysis of stylised and bank-level balance sheet data shows that – irrespective of the adjustment options chosen by a bank – substitution of bank deposits with a central bank digital currency would likely trigger an offsetting liquidity-providing operation by the central bank to ensure that the economy-wide liquidity situation is kept unchanged. A digital euro could also potentially alter economy-wide bank run dynamics. While an unconstrained supply of digital euro could lead to an increase in the scale and speed of a system-wide bank run, limits on individual holdings of a digital euro could mitigate such an outcome. The paper concludes that, if appropriately designed, the impact of introducing a digital euro on monetary policy transmission and financial stability appears to be manageable.

1 Introduction

In July 2021 the Eurosystem decided to launch the investigation phase of a two-year project aimed at ensuring that the Eurosystem would be ready to issue a digital euro if needed.[1] A digital euro could support the Eurosystem's objectives by providing citizens with access to a safe form of money in an increasingly digitalised world and contribute to its strategic autonomy by providing an alternative to foreign payment providers for fast and efficient payments in Europe and beyond (ECB, 2020a). At the same time, a digital euro, if not properly designed, could result in the substitution of bank deposits and foster bank disintermediation, which in turn could have implications for financial stability and monetary policy transmission (ECB, 2020a). Furthermore, in periods of stress, systemic bank runs could occur more easily or faster in the presence of a CBDC (Broadbent, 2016; Callesen, 2017).[2]

Anticipating the impact of a digital euro on monetary policy transmission and financial stability is challenging because of the uncertainty surrounding its demand, design and the prevailing environment in which it may be introduced. While the Eurosystem has stated that any digital euro would be intended for retail payments use only **(ECB, 2020a)**, many other design features that will determine the convenience and ease of use of a digital euro, which have a direct impact on demand for it, are still to be decided. The economic and financial environment that would prevail at the time a digital euro might be issued is also uncertain, including the monetary policy environment and the potential availability of alternative digital moneys. Lastly, no major advanced economy to date has introduced a CBDC, resulting in a lack of data that could be used in empirical analyses. Therefore, at this stage, it is particularly challenging to estimate the effects of a digital euro and design the options to manage its take-up.

Reflecting that uncertainty, this paper analyses the impact of a digital euro by considering several illustrative take-up scenarios. In view of the high uncertainty surrounding the design of a digital euro, such a scenario approach seems to be well suited to arrive at a range of estimates by imposing certain – albeit arbitrary – assumptions on the degree of substitutability between different forms of money (bank deposits, cash and digital euro). Based on aggregate balance sheet data and assumptions regarding different demand intensities in normal times, the effects of safeguards such as a cap on digital euro holdings are illustrated as well. The study

1 See "Eurosystem launches digital euro project", ECB press release,14 July 2021.

2 Although less widely discussed, CBDCs also represent numerous potential benefits to bank and financial stability, as they may: (i) facilitate a separation of safe payment-based banking activities from risky credit provision, potentially reducing the fragility of the banking system (Haldane, 2021); (ii) provide a useful crisis management tool when it provides real time information on deposit flights that may be used to calm markets before banking crisis materialise (Keister and Monnet, 2020); (iii) help in avoiding banking crises by making bank resolution easier and faster, reducing the contagion effects of bank failures, and weakening ex-ante run incentives (Kumhof and Noone, 2021); and (iv) increase competition in the monopolistic deposit market, improving prices and services for consumers (Andolfatto, 2021).

also investigates the potential dynamics of the demand for a digital euro that could emerge in stressed times.

Aggregate and bank-level data are used to show the mechanisms through which the banking sector adjusts to a digital euro and to illustrate banks' responses. First, a stylised balance sheet approach allows us to identify the different options the banking sector has to adjust when a digital euro is put into circulation and the channels through which it could affect bank intermediation on aggregate. Then, bank-level data are used to illustrate how different factors such as bank regulatory constraints (e.g. liquidity regulation, Eurosystem collateral requirements) and institutional specificities (e.g. the deposit ratio, the funding structure) may affect banks' responses and, consequently, the extent to which a digital euro could alter bank intermediation. Market reactions to digital euro announcements are also used as a first test of these findings. Finally, the paper analyses the consequences a digital euro could have for the scale and speed of economy-wide bank runs.

The rest of the paper is structured as follows. Section 2 introduces a selected number of illustrative digital euro take-up scenarios, which – under some arbitrary assumptions regarding substitutability of different forms of money – range from €490 billion to €7.5 trillion based on current data, if demand is left unconstrained. This section also investigates the effects of a cap on take-up. Section 3 gives an overview of the impact a digital euro could have on bank intermediation in normal times based on aggregate and bank-level balance sheet data. It concludes that – irrespective of the adjustment options a bank chooses – the central bank would be able to ensure, through an offsetting liquidity-providing operation, that the economy-wide liquidity situation remains unchanged. Section 4 studies some of the mechanisms through which a digital euro could alter economy-wide bank run dynamics. While an unconstrained supply of digital euro could lead to an increase in the scale and speed of a system-wide bank run, limits on individual holdings of a digital euro would prevent such an outcome. Section 5 concludes.

2 CBDC demand and illustrative scenarios

When gauging the effects of a digital euro on bank intermediation, its expected take-up will be key. To the extent that the public decides to convert bank money into digital euro, the expected take-up will determine the size of deposit outflows for the banking sector and may thereby affect the capacity of banks to intermediate credit to the private sector (for a detailed analysis see Chapter 3). As a first step, it is therefore paramount to assess the possible demand for a digital euro.

Various sources of uncertainty make the task of estimating future demand for a digital euro particularly challenging. The lack of experience with CBDCs, especially in advanced economies, means no empirical data on actual demand exists. In addition, many important design features of a potential digital euro that could affect demand have not yet been decided (ECB, 2020a, Bindseil, Panetta and Tirol, 2021). Lastly, there is significant uncertainty about the environment that would prevail by the time a digital euro were introduced – for example, what other forms of digital payment or token might be in widespread use at that time and what the broader monetary policy environment would look like. These reasons explain why coming up with any realistic estimate for a digital euro take-up at this stage is particularly challenging.

Recent studies have proposed at least three different approaches to estimate the potential demand for CBDCs. First, empirical models and survey data have provided useful insights. Li (2021) applies a structural demand model to Canadian survey data to quantify household demand for CBDC as a store of value.[3] Bijlsma et al. (2021) directly ask survey respondents in the Netherlands if they would open a CBDC account.[4] Second, other authors derive the demand for CBDC by means of theoretical macroeconomic models. Burlon et al. (2021) specify and calibrate to euro area quarterly data a Dynamic Stochastic General Equilibrium (DSGE) model that replicates the existing evidence on the estimated impact of digital euro news on euro area bank stock prices to determine the demand for CBDC under different design options (see also Section 4.2).[5] This and other papers highlight the importance of parameters such as the elasticity of substitution between CBDC and bank deposits in determining CBDC take-up (e.g. Assenmacher et al., 2021). Third, an estimate of digital euro take-up can be derived from illustrative take-up scenarios based on certain assumptions and the use of payments and balance sheet data. Although

3 This paper predicts CBDC holdings between 4% and 55% of liquid assets holdings.

4 Approximately 50% of the survey respondents in the Netherlands would do so, where most said they would transfer up to €500 to a CBDC current account and, depending on the remuneration, €1,000 to €20,000 to a CBDC savings account.

5 Under the proposed baseline calibration for the euro area, in equilibrium the digital euro take-up would range from 15% to 65% of quarterly real GDP. After having rounded up the size of the population in the euro area to 340 million citizens and average quarterly GDP in 2021 to EUR 3 trillion, this range of values would be equivalent to €0.45 trillion – €1.95 trillion. For further details, see Burlon, L., Montes-Galdón, C., Muñoz, M. A., and Smets., F. (2022), "The optimal quantity of CBDC in a bank-based economy", CEPR discussion papers.

uncertainty around the assumptions on which these scenarios are based is high, some of the scenarios that have been proposed consist of a bank deposit outflow of 5% to 10% of bank assets (García et al., 2020) and 20% of household and non-financial deposits (Bank of England, 2021).

This section presents some illustrative take-up scenarios for the euro area to study the potential impact of a digital euro on bank intermediation capacity. These scenarios are based on aggregate balance sheet data and make assumptions regarding different demand intensities and the degree of substitutability between different forms of money (bank deposits, cash and digital euro). In addition, take-up for a scenario in which the demand for digital euro is limited by a cap that is imposed by the authorities is also calculated**.** While relying to a large extent on ad-hoc assumptions, this methodology has a number of benefits as the resulting take-up estimates (i) are based on a comprehensive set of data that comprises interest rates, funding costs, and aggregate balance sheet information from all key institutional sectors; (ii) their construction and application are easy to follow and interpret; and (iii) they can inform mechanical counterfactual analysis to identify how take-up changes in response to modifications in the calibration and/or combination of CBDC usage limits and remuneration.

2.1 Illustrative digital euro demand scenarios

Demand for a digital euro will very much depend on its design features and the environment prevailing at the time of its introduction, including interest rates and the existence of alternative forms of money. Certain digital euro design features such as remuneration could largely incentivise or deter take-up: clearly, a non-remunerated CBDC would be less attractive in a positive interest rate environment than in a situation in which (at least some) money holders face negative remuneration for their cash holdings. Similarly, it is conceivable that more availability of alternative forms of digital money could weigh on the demand for a digital euro. The interaction of these and other dimensions, such as convenience of use and the ongoing trend towards a more digital economy, would result in a multitude of possible demand scenarios, requiring the use of elasticities that are difficult to estimate or calibrate. Final take-up would also depend on the interaction between all the other actors in the system, notably banks and the central bank. Striving for simplicity, while at the same time maintaining the illustrative purpose of the exercise, two well differentiated scenarios are developed.

Two differentiated hypothetical digital euro demand scenarios in non-stressed times and a showcase of restricted supply are considered. The choice of these scenarios is not based on their likelihood and, thus, should not be seen as an attempt to forecast future demand for a digital euro. They merely aim to numerically illustrate two markedly different levels of demand for a digital euro: (A) a “moderate demand for retail payments only”; and (B) a “large demand”, resulting from digital euro being intensively used as means of payment and store of value. A third

scenario (C) is considered in order to illustrate the size of a "capped take-up".[6,7] Scenarios A and B aim to illustrate two distinct demand levels in a situation of elastic supply of digital euro (akin to banknotes), whereas in scenario C supply would be limited. These scenarios illustrate demand for a digital euro in a non-stressed situation under no remuneration.[8] In a negative interest rate environment, an unrestricted supply (i.e. with no take-up limits) of a non-remunerated digital euro would likely entail (almost) unlimited demand by those agents facing negative remuneration in their bank deposits (currently these include non-bank financial institutions (NBFIs) and large corporations). This is because such a CBDC would offer a higher degree of safety and a more attractive yield than other assets. Scenarios A and B should therefore be considered as illustrating the potential demand for a non-remunerated digital euro in an interest rate environment similar to that observed in 2021 (**Table 1**).[9] Although the scenarios presented in this section rely on particular assumptions, the methodology easily allows for updating the underlying balance sheet data or changing the assumed elasticities to whatever monetary policy configuration may be in place.

Table 1

Interest rate environment in Q3 2021

	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

Sources: ECB and IHS Markit.
Notes: The table shows interest rates relevant for the paper calculated as average across Q3 2021.
The Markit iBoxx MFI bonds yields is calculated as an average of the monthly average annual yield to maturity weighted by nominal amount of EA mfi bonds which have maturity higher than 2 years of iBoxx bonds.

Under the "moderate demand" scenario A, the digital euro is assumed to only partially replace other retail means of payment even if supply is unconstrained. In our calculation, we focus on the substitution of banknotes and overnight euro-denominated deposits by each sector (**Table 2**). For households the following substitution shares for retail payments are assumed: (i) 50% of the value of banknotes used for retail payments, (ii) 25% of the transaction value paid with cards and (iii) 75% of the transaction value settled with other means of payment, such as

6 Section 4 discusses different options to design such limits and their potential implications for the scale and speed of simulated economy-wide bank runs.

7 In the event a digital euro was issued, the Eurosystem would have the ability to control the amount of digital euro in circulation (see Requirement 8 in ECB, 2020a). No decision has yet been made on the safeguards that should be adopted in order to meet this requirement.

8 The potential implications of digital euro demand in stressed times for an economy-wide bank run are considered in Section 4.1.

9 The scenarios are calculated on current balance sheet data, which are influenced by current interest rate levels. They may be interpreted as reflecting a situation in which rates on alternative non-monetary assets have returned to zero whereas deposit rates remain close to current levels, so that a digital euro would substitute only for money-like assets but not for bonds and other stores of value.

electronic money.[10, 11] To obtain the total take-up of digital euro, a transaction velocity of digital euro of 7 is assumed, equal to that of cash when used for retail payments, reflecting that the amount of digital euro necessary to carry out retail payments is likely to be smaller than the transaction value itself.[12] To remain parsimonious, the share of substituted deposits and banknotes of non-financial corporations (NFC) is assumed to be equal to that of households. Furthermore, NBFIs do not demand digital euro for retail payments. Non-residents' demand for digital euro for retail payments is assumed to replace only banknotes, linked to their visits to the euro area.[13]

10 The category "Cards" includes credit and debit cards. The category "Others" refers to payments with mobile phones, bank cheques, credit transfers, direct debits and other (unidentified) payment instruments, and includes the answer "Don't know". Due to their low frequency of use, these instruments have been grouped into a single category.

11 Data on these retail transactions are obtained from the "Study on the payment attitudes of consumers in the euro area" (ECB, 2020b).

12 The transaction-velocity of cash has been computed as the share of the transaction value of retail payments in cash (ECB, 2020b) over banknotes used for transactions (Zamora-Pérez, A., 2021).

13 Banknotes in circulation in non-euro area microstates using euro (e.g. San Marino, Andorra, Monaco and Vatican City) are estimated to be below €1 billion. Including their banknote substitution for digital euro has a negligible impact on our calculations.

Table 2

Hypothetical scenarios of digital euro take-up

(EUR billions)

		Households	NFCs	Nonbanks	Foreign	Total
Moderate take-up for retail payments only ***(no holding restrictions and no remuneration)***	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 deposits	120	60	0	0	180
	From banknotes	158	30	0	120	308
Large take-up for retail payments & storage of value ***(no holding restrictions and no remuneration)***	Assumptions	70% of banknotes and 50% of overnight deposits	70% of banknotes + 50% overnight deposits	90% of overnight deposits	Banknotes: 120 retail banknotes + 80% remaining banknotes held by non-residents Deposits: 90%	
	Overall demand	**3127**	**1383**	**776**	**2204**	**7490**
	From overnight deposits	2594	1283	776	1699	6352
	From banknotes	533	100	0	505	1138
Capped take-up	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 deposits	647	0	0	0	647
	From banknotes	380	0	0	120	500

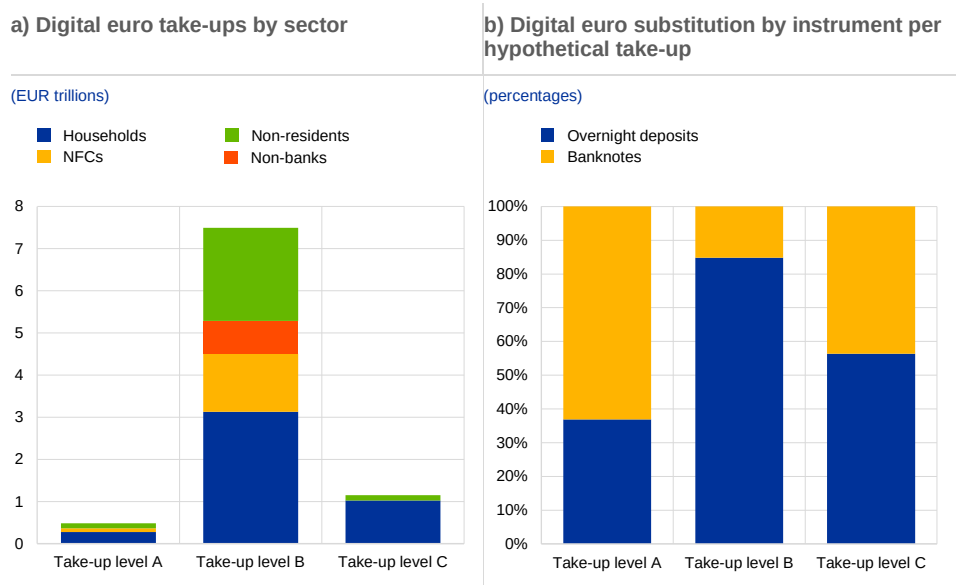
Sources: ECB (SPACE 2019 survey, BSI and QSA) and ECB calculations.
Latest observation: Q3 2021.

Under the assumptions for the "moderate demand for retail payments only" scenario (A), the take-up of digital euro would be around €490 billion, with domestic demand amounting to just about €370 billion. Foreign demand would result in a substitution of banknotes of around €120 billion (**Chart 1, panel a)** and

Table 2). Overall, digital euro would replace banknotes and deposits in approximately equal shares (**Chart 1, panel b**).

Chart 1

Hypothetical digital euro demand scenarios



Source: ECB calculations.
Note: The chart on the right shows what proportion of the total take-up in the chart on the left substitutes banknotes or overnight deposits.

The "large demand" scenario (B) illustrates an intense use of digital euro as a store of value coupled with an increased use for retail payments and assumes unlimited supply. Under this scenario, the bulk of the demand for digital euro is driven by an assumed preference for having access to the safety of central bank money. First, both households and NFCs are assumed to replace 70% of their banknote holdings. Full substitution is not expected, as a residual preference for holding banknotes is considered, especially by some demographic groups.[14] In addition, estimates show that banknotes may also be used in the shadow/illicit economy.[15] Secondly, it is assumed that households and NFCs would replace 50% of their deposits with digital euro. In contrast with Scenario A, which only considers demand for retail payments purposes, deposit substitution by NBFIs and non-residents is assumed to be proportionally larger (90%), resulting from a large demand for digital euro as a store of value by these sectors. This follows from the assumption that these sectors would always have a higher preference for holding digital euro, which would allow them access – like banks – to the safety of central bank money to store their liquidity.

The assumptions for scenario B ("large demand") generate an overall demand of €7.5 trillion, of which €5.3 trillion stems from domestic demand (Chart 1A and Table 2). Households would account for the largest share of the domestic take-

14 We assume that a 70% substitution for banknotes by NFCs and households (HH) is large enough to already take into account that the coronavirus pandemic has accelerated technological adoption by larger groups of people, decreasing the demand for banknotes.

15 See Reimers et al (2020) and Rogoff (1998).

up, with €3.1 trillion. In terms of instrument substitution, the bulk of the overall demand for digital euro would stem from overnight euro-denominated deposits.

Under the "capped" scenario (C), it is assumed that all residents exhaust a €3,000 limit on their individual holdings whereas visiting non-residents can hold digital euro exclusively for retail payment purposes.[16, 17] Visiting non-residents' demand is constrained to retail payments only as no store of value motive for this group is assumed. In this scenario neither NBFIs nor NFCs would be allowed to accumulate digital euro balances. Nevertheless, merchants could receive payments in digital euro thanks to a functionality that would transform those payments into bank deposits immediately.

Assuming a full exhaustion of the limit on individual holdings, a digital euro uptake of €3,000 by each of the approximately 340 million inhabitants of the euro area amounts to a total demand of €1.03 trillion. Demand by visiting non-residents (i.e. for retail payments only) is calibrated to be around €120 billion like in scenario A. Thus, the overall digital euro demand would result in approximately €1.15 trillion (**Chart 1, panel a**). Assuming that – like in scenario A – 50% of banknotes held by euro area households would be substituted by digital euro (around €380 billion), the remaining amount would imply a substitution of 12.5% for households' euro-denominated overnight deposits. The figures should, however, be understood as an upper bound of demand for digital euro under this scenario, as in practice there is a relevant proportion of citizens that do not hold €3,000 in bank deposits or cash (**Chart 2**). Hence, these citizens would not be able to exhaust the €3,000 limit per person.

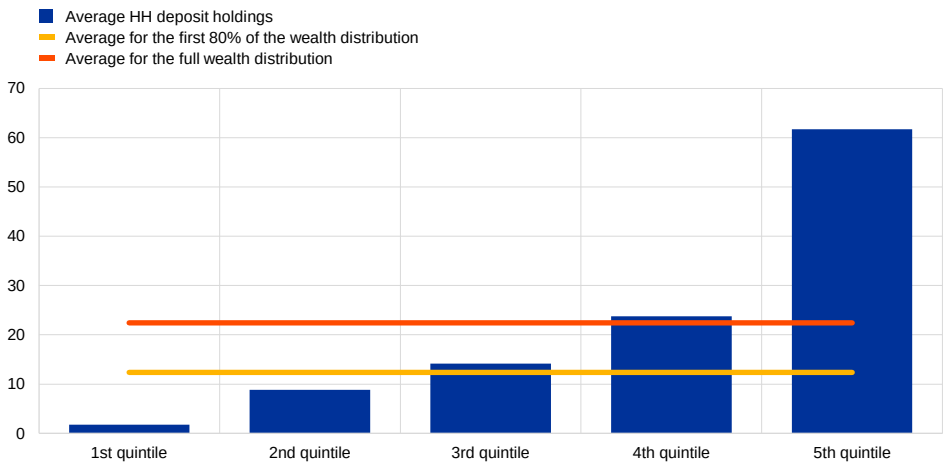
16 As argued by Bindseil and Panetta (2020), a per capita amount of €3,000 could be interpreted as covering the average monthly net income of euro area households, such that the normal payment function of money would be covered. In Chart 2, we investigate the sensitivity of deposit substitution to alternative values of the per-capita limit amount.

17 Panetta (2018) suggests to "set a ceiling on the amount of CBDC that each individual investor can hold". In normal times, this limit on individual digital euro holdings could be interpreted as a hard limit (i.e. a limit beyond which no additional individual digital euro holdings are allowed) or as a soft limit associated with a tiered remuneration scheme (i.e. a limit beyond which additional holdings are allowed but only at a dissuasive interest rate). See Bindseil (2020) and Bindseil and Panetta (2020) for a proposal on how a two-tiered remuneration scheme with a dissuasive rate on tier 2 CBDC holdings could be designed. Calibration alternatives to the €3,000 limit on individual holdings are considered in Sections 3 and 4. Section 4 discusses the different implications of hard and soft limits on individual CBDC holdings for the case of simulated system-wide bank runs.

Chart 2

Households' deposits across wealth quantiles

(average deposit holdings across quantiles, EUR thousands)

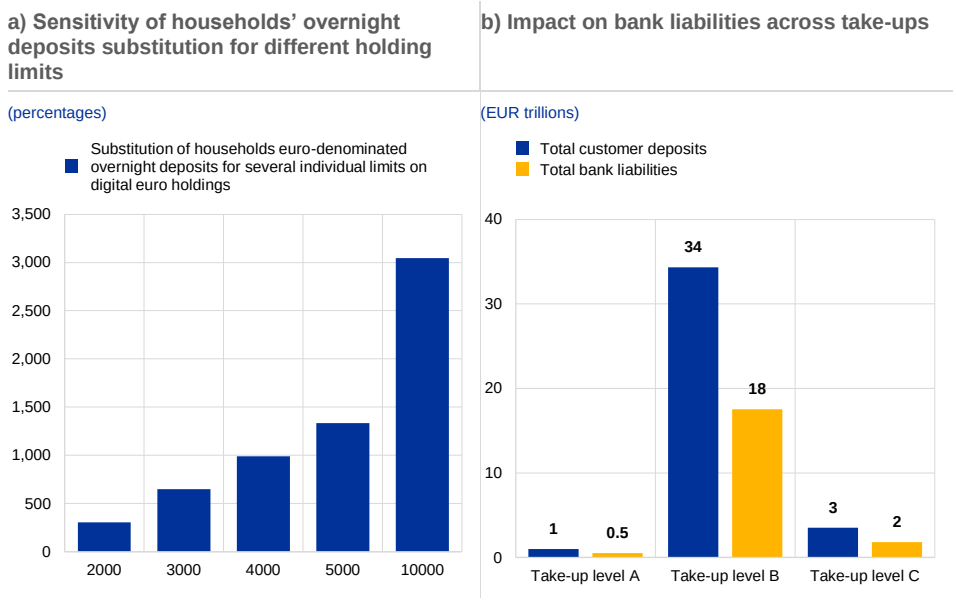


Source: ECB.
Notes: The chart shows average household (HH) deposits across wealth quintiles in the euro area. The red horizontal line shows the average household deposits across all quintiles, whereas the yellow horizontal line shows the average household deposits across the first four wealth quintiles.

Increasing or decreasing the limit on individual holdings by €1,000 changes the deposit substitution by about 2% of total customer deposits (almost 1% of total bank liabilities). As we work from a fixed share of banknotes substitution, any change to the limit on individual holdings will, by assumption, only be reflected in a substitution of digital euro for deposits. For every €1,000 increase in the holding limit, the substitution away from households' euro-denominated overnight deposits is about €340 billion (**Chart 3, panel a**) and around 7% in terms of the stock of households' euro-denominated overnight deposits.

Chart 3

Deposit sensitivity to holding limits and impact on bank liabilities



Note: Total customer deposits includes all deposit liabilities except those between euro area banks.

Based on the above illustrative take-up scenarios, deposit substitution would range between 0.5% to 18% of aggregate euro area bank liabilities, measured at end of September 2021. These figures are subject to a number of caveats. First, the data on which this exercise is based will not match balance sheets at the point in time when a digital euro may actually be introduced. Second, substitution shares are based on plausibility considerations and cannot be checked against any data at the moment. Third, these figures are obtained by considering only a static substitution away from deposits at the euro area aggregate level (**Chart 3, panel b**). They do not include general equilibrium effects such as reactions on the side of banks, which could change conditions and functionality of the services they offer, nor any adjustment in interest rates that could result from a decrease in deposits as a funding source for banks. Moreover, they do not reflect any potential reaction of the central bank that may aim to offset unwanted effects resulting from the introduction of a CBDC on the monetary policy stance, which could result in a creation of new bank deposits. Therefore, these figures do not measure the overall impact on banks' intermediation capacity, but only a mechanical first-round impact.

3 Considerations on changes to structural bank intermediation

This section investigates the implications of a digital euro on bank balance sheets, providing some preliminary insights into the possible impact of rolling out a CBDC on bank intermediation. As a digital euro can potentially substitute for a portion of bank deposits, the framework distinguishes between four different adjustment channels. The balance sheet mechanics show that – except when the introduction of a digital euro is matched by a reduction in excess reserves or banknotes – the central bank would need to inject liquidity to accommodate the demand for the CBDC.

The analysis in Section 3.1 assumes that liquidity regulation and collateral constraints, among other frictions, are not binding, allowing the central bank to fully offset the effects of CBDC demand on the banking sector. This conclusion corresponds to the equivalence results that have been offered in the academic literature.[18] While the existence of frictions, such as collateral and liquidity constraints, modifies these conclusions, available data and estimates of the impact of digital euro news on banks' stock prices suggest that the effects of a digital euro on the intermediation capacity of the euro area banking sector would likely be manageable.[19] Importantly, heterogeneities within the banking system imply that the impact of a digital euro can vary significantly across credit institutions (Section 3.2).[20]

3.1 A stylised balance sheet approach

Balance sheet relations provide a consistent framework to analyse how the introduction of a digital euro would alter banks' balance sheet positions and affect banks' intermediation capacity. The mechanisms through which a digital euro is put into circulation, with banks' reserves at the central bank as the immediate counter-position, provide an intuitive starting point for this analysis.[21] In resemblance to banknotes, it is assumed that banks intermediate the distribution of digital euro. This implies that banks must first obtain the digital euro from the Eurosystem and then "resell" it to the final holder. In doing so, banks pay the Eurosystem with reserves and debit the bank account of the final holder (**Figure 1**). While both final

18 See, for example, Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al. (2020).

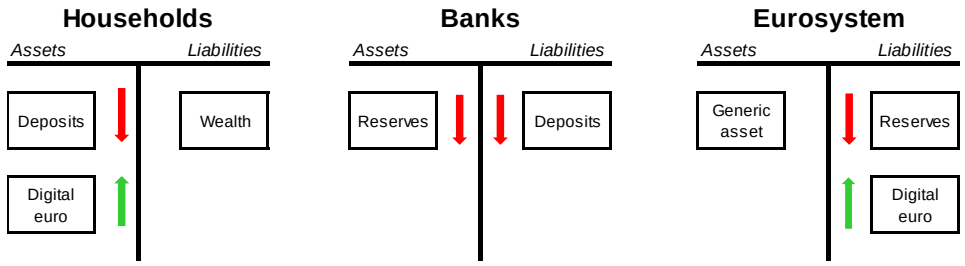
19 Some of the imperfections that are implicitly or explicitly incorporated in this part of the analysis include imperfect competition in the euro area banking sector, liquidity regulation and Eurosystem collateral requirements, among others.

20 Some of the bank-level factors that, according to the analysis presented in Section 3.2, would affect the impact that introducing a digital euro has on an individual credit institution include the business model and the deposit ratio, among others.

21 In this section, the word "reserves" refers to banks' deposits with the Eurosystem, and in particular to those in excess of reserve requirements. The volume of required reserves is currently negligible, representing just above 3% of total banks' reserves with the Eurosystem.

holders and banks could obtain digital euro in exchange for banknotes, beyond this channel, banks need to hold reserves to put digital euro in circulation.[22]

Figure 1
The mechanics of putting digital euro into circulation



There are four channels through which banks' balance sheets would adjust to the introduction of a digital euro. Specifically, in order to put digital euro in circulation, banks can: *(I)* return (or intermediate the return of) banknotes to the Eurosystem. Alternatively, they can *(II)* reduce their stock of excess reserves with the Eurosystem. Banks can also obtain additional reserves via *(III)* increasing their borrowing from the Eurosystem, or *(IV)* seling assets to the Eurosystem. From the Eurosystem's viewpoint, options *I* and *II* represent a swap from existing Eurosystem liabilities (bank reserves or banknotes) to digital euro, while Options *III* and *IV* represent an asset expansion in a situation in which the issuance of digital euro is larger than the reduction in reserves or banknotes. All adjustment options strictly linked to the introduction of a digital euro require the involvement of the Eurosystem balance sheet.

Which of these adjustment strategies banks will actually use depends on the preferences of customers, the choices of banks and the policies of the Eurosystem. Depending on the size of the deposit substitution (for different scenarios see Section 2), banks, owing to profitability and regulatory considerations, may have a preference for a specific adjustment course and may also engage in additional re-optimisations of their balance sheets. Finally, the Eurosystem plays a key role: first, it influences the size of its balance sheet by steering the quantity of digital euro in circulation through the attractiveness of holding digital euro, or by imposing hard limits; second, the Eurosystem decides on the composition of its assets and its collateral policy.

3.1.1 Adjustment channels

This subsection considers the adjustment mechanisms linked to the introduction of CBDC. These channels are not exclusive and can operate in parallel to each other. However, to facilitate the exposition, each channel is investigated separately, under

[22] Theoretically, the digital euro could be put in circulation also via intermediaries other than banks with an account at the central bank. To the extent that the intermediaries would need to acquire the digital euro with reserves (or banknotes) and the final holder would need to pay with bank deposits (or banknotes), the assumption of banks as the only distributing agents can be maintained without loss of generality.

the assumption that there are no market frictions and that regulatory constraints are not binding. The role of constraints and frictions in the adjustment process is discussed in Section 3.1.3 and throughout the rest of Section 3.

Channel I: Banknotes for digital euro

Replacing banknotes with digital euro amounts to a swap between two types of Eurosystem liabilities, with no implications for banks' balance sheets. Banks would act merely as distributing agents: money holders would return banknotes to the Eurosystem and exchange them for digital euro, leaving other Eurosystem assets and liabilities untouched.

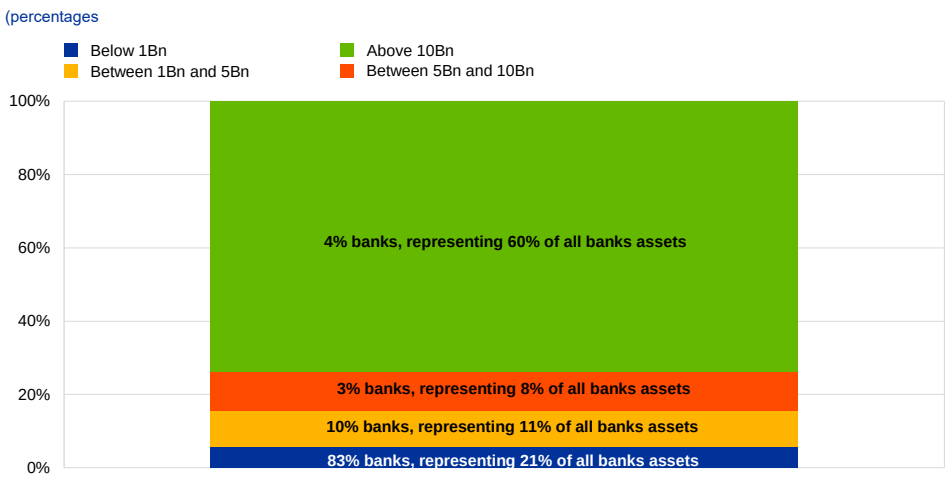
Channel II: Existing bank reserves for digital euro

Banks reduce their holdings of reserves with the Eurosystem in an amount equal to the deposit loss, without further impacting other items on the asset side of their balance sheets. Reserves decline as banks use them to acquire digital euro from the Eurosystem in order to pass it on to their customers in exchange for deposits. Other bank assets remain unchanged. For the Eurosystem, this option represents a swap in its liabilities, with digital euro covering the reduction in bank reserves (**Figure 1**).

On the individual level, banks would likely need to engage in interbank borrowing given that customers' demand for digital euro may differ across banks and reserves are distributed unequally in the market. In the third quarter of 2021, 4% of euro area banks, representing 60% of the main assets of the banking sector, accumulated more than 74% of excess reserves in the euro area (**Chart 4**).

Chart 4

Distribution of excess reserves across euro area banks



Source: ECB and iBSI.
Notes: Excess reserves at an individual bank level calculated as an average across maintenance period 5 in 2021. Main assets include loans, securities held, claims on other banks and the Eurosystem.

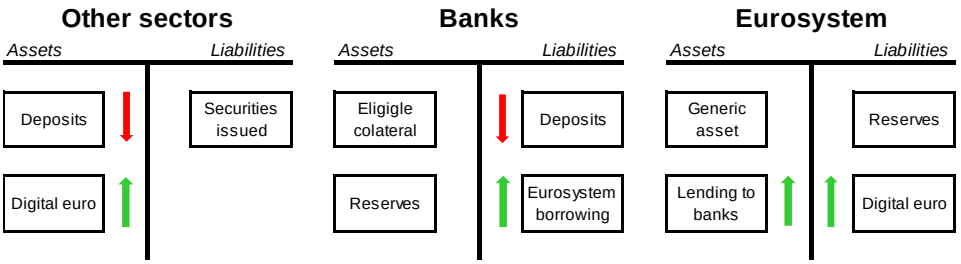
Chanel III: Central bank borrowing for digital euro

Banks replace the deposits transformed into digital euro with increased Eurosystem borrowing, with no further changes in other balance sheet items. Either because they lack the necessary amount of reserves or because they prefer to keep a certain amount of them, banks may be willing to borrow additional reserves from the Eurosystem to meet their customers' demand for digital euro. In such a case, the Eurosystem would instantaneously recycle back to banks the funding lost because of the transformation of deposits into digital euro. This results in a lengthening of the Eurosystem's balance sheet equal in size to the deposit substitution, which avoids a contraction in bank credit to the economy (**Figure 2**).[23]

[23] The standard Eurosystem operational framework offers regular open market operations consisting of one-week liquidity-providing operations in euro (main refinancing operations, or MROs) as well as three-month liquidity-providing operations in euro (longer-term refinancing operations, or LTROs). The Eurosystem may also conduct non-regular longer-term operations with longer maturities.

Figure 2

Banks increase their borrowing from the Eurosystem



Channel IV: Assets for digital euro

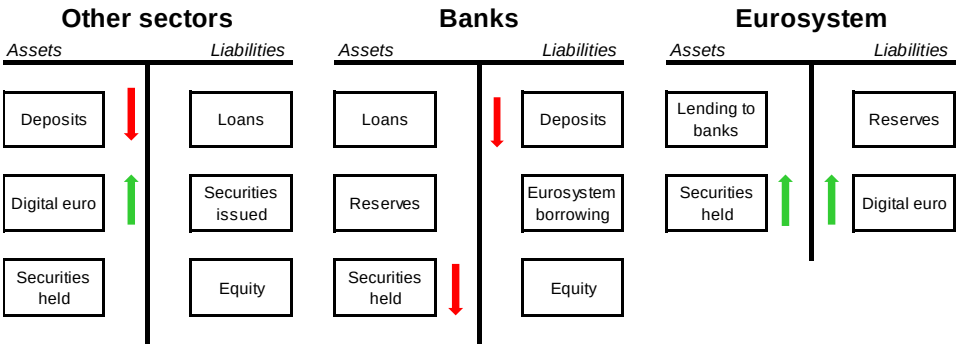
As an alternative to borrowing, banks can also obtain reserves by selling assets to the Eurosystem, either from their own portfolios or on behalf of their customers. When acquiring assets, the Eurosystem pays the seller with reserves. Banks can then use the newly created reserves to acquire from the Eurosystem the digital euro demanded by their customers. When selling assets to the Eurosystem, banks can do so: *(IV.a)* from their own portfolio, or *(IV.b)* on behalf of their customers, the latter resulting in the creation of new customer deposits. Option *IV.a* leaves the amount of money in the hands of the public unchanged (as, from the money holders' perspective, the decrease in deposits is offset by the increase in CBDC), while Option *IV.b* results in an increase in the volume of money in the hands of the public, as it entails the creation of new customer deposits, which adds to the issuance of CBDC.

Option IV.a: Banks sell part of their own assets to the Eurosystem

Banks' deposit loss is matched by a reduction in banks' assets. Banks sell assets to the Eurosystem to obtain reserves to acquire the digital euro demanded by their customers; customers receive the digital euro in exchange for deposits. Therefore, putting digital euro in circulation via this channel results in a simultaneous contraction of bank deposits and assets. The contraction in banks' balance sheet is commensurate to the expansion of the Eurosystem's balance sheet, leaving the balance sheet size of the MFI sector unchanged (**Figure 3**), as well as the amount of money in the hands of the public.

Figure 3

Banks sell part of their own assets to the Eurosystem



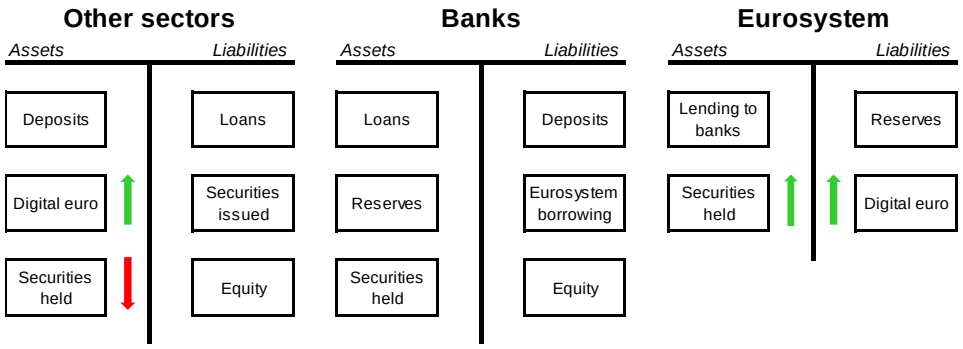
Option IV.b: Banks sell assets to the Eurosystem on behalf of other sectors

While the volume of bank deposits in this option is not affected by the issuance of digital euro, the overall amount of money in the hands of the public increases. As the first step of this option, a bank acquires an asset from another sector. In doing so, it typically pays for it by crediting a deposit account held by the seller, hence creating deposits. Subsequently, the bank sells the asset to the Eurosystem, thereby obtaining the reserves needed to acquire the digital euro demanded by its customers. If this is the only channel to put digital euro in circulation, the aggregate volume of bank deposits is not affected: the loss of deposits caused by those customers transforming their deposits into digital euro is fully offset by the increase in deposit balances of those investors selling assets to the banks (**Figure 4**).[24]

[24] This option could eventually result in an increase in market-based funding if a part of the newly created deposits is transformed, for instance, into bank bonds.

Figure 4

The Eurosystem purchases assets from other sectors via banks



3.1.2 Combining the adjustment channels with the illustrative demand scenarios

The adjustment channels that have been just exposed can be combined with the illustrative demand scenarios discussed in Section 2 to unveil potential limits. This exercise builds on data as of September 2021 and depends on the current monetary policy setting, which is likely to change by the time a potential digital euro may be introduced. Therefore, the analysis in this section merely illustrates how such a cross-check can be conducted and does not offer definitive conclusions. Moreover, the exercise focuses on the immediate impact and neglects general equilibrium considerations and price adjustments.

A rough quantification of the respective limits can be derived for each adjustment channel, on the basis of current conditions. For instance, the aggregate level of excess reserves in the system (about €4.3 trillion in September 2021) is the natural limit for Channel *II* (See **Annex B** for an overview of the aggregate positions of the main euro area institutional sectors). Adjusting balance sheet through central bank liquidity operations (as described in Channel *III*) would reach its exhaustion once banks run out of collateral, while the space for Channels *IV.a* and *IV.b* would depend on the availability of assets eligible for Eurosystem purchases.[25]

The simple quantification of the limits of the above stylised adjustment channels suggests that the banking sector could easily accommodate a moderate demand for CBDC for retail payments only. The illustrative level of

[25] The figures presented in Chart 5 represent rough maximum limits based on current balance sheet data and do not account for planned or future changes in the monetary environment. For instance, everything else equal, the level of excess reserves would be considerably reduced upon repayment of banks' borrowings via Targeted Long-Term Refinancing Operations (TLTRO) in the coming years. A termination of the current reinvestment policy for APP/PEPP purchases could further reduce the availability of excess reserves in the system. The figures also assume a full mobilisation of potentially eligible collateral and purchasable securities beyond the restrictions resulting from current rules. For instance, the calculated limits for both modalities of Option IV do not consider issuer limits currently in place for APP purchases. Finally, cross-bank heterogeneity is not taken into account.

deposit substitution resulting from Scenario A (below €200 billion, Chart 5.A) would lie far below the absorption limit of all adjustment options.

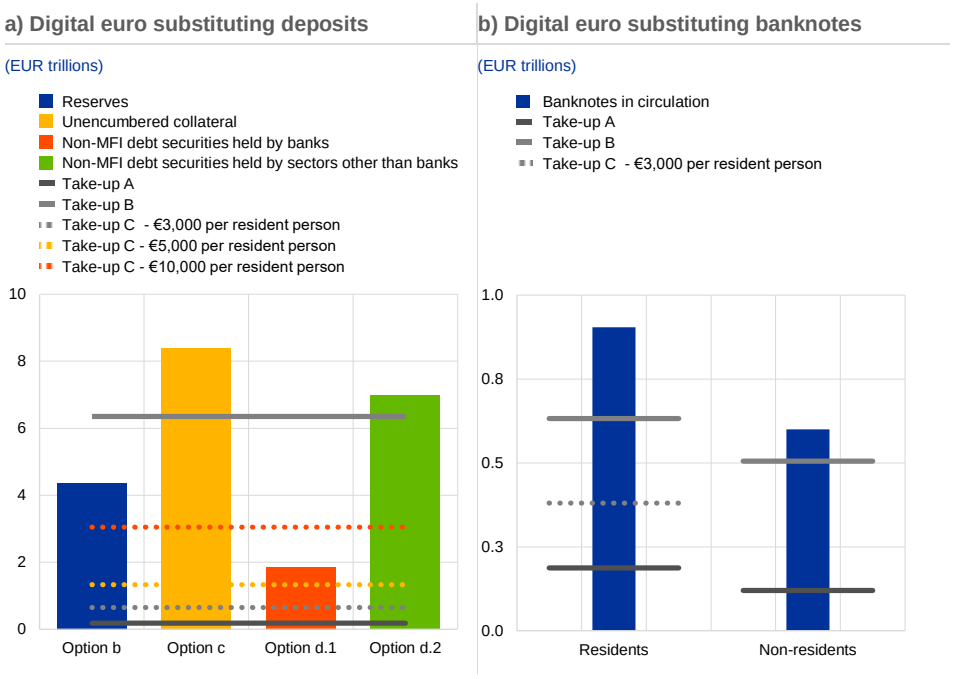
A large unconstrained demand (as illustrated by Scenario B) would, however, require a significant expansion of the Eurosystem's balance sheet. A take-up of digital euro of the magnitude illustrated by Scenario B (causing a more than €6 trillion deposit substitution) would go well beyond the absorption capacity of Channel II (adjustment via existing reserves), even under the assumption of a fully efficient interbank market. Therefore, other channels (III and/or IV), entailing the expansion of the Eurosystem balance sheet, would be needed.

The rough estimations linked to Scenario B suggest that an optimal combination of all four adjustment channels could still be compatible with an orderly adjustment process (Chart 5). Nonetheless, the distance to the overall feasible adjustment limit would be reduced, especially taking into account that the adjustment channels are not mutually independent from each other, e.g. a large use of collateral for Eurosystem borrowing (Option III) would reduce the effective limit of the purchases options (Options IV.a and IV.b). Extending the analysis in order to account for frictions that are present in reality becomes particularly relevant (see Sections 3.1.3 and 3.2).

When considering scenarios where demand is capped, all adjustment channels would, on aggregate, offer the possibility to accommodate take-ups of up to €3,000 or even €5,000 per resident. A demand of €3,000 per resident would result in an aggregate amount of deposit substitution (about €650 billion, as per illustrative take-up C) well below the exhaustion limit of all the adjustment options (**Chart 5, panel a**). The large absorption leeway across adjustment options would also be consistent with the expectation that such a take-up should not result in aggregate balance sheet dynamics that would curtail banks' profitability and their capacity to provide credit to the economy (see also **Section 3.3.3**). Likewise, a potentially large substitution of banknotes compatible with a €3,000 digital euro take-up per person (take-up Scenario C) would still leave a large amount of banknotes in circulation (**Chart 5, panel b**). Relaxing the safeguard on individual holdings somewhat, e.g. from €3,000 to €5,000, would still be compatible with all adjustment options being individually able to cope with the adjustment. However, the distance to the individual option limit would be reduced. Furthermore, as take-up amounts increase, the absorption limits of some of the adjustment options may get particularly reduced or become binding for some individual banks or jurisdictions.

Chart 5

Digital euro and possible adjustment channels



Source: ECB and ECB calculations.
Notes: Panel a): *Option II*: outstanding amount of bank reserves (see Annex B). *Option III*: A larger generic haircut (40%) is applied to the value of bank holdings of potentially eligible unencumbered securities and loans in order to account for the assumed uneven quality of those assets. The value of potentially eligible unencumbered assets is estimated to amount to €14 trillion (subtracting the ratio of encumbered assets for significant institutions, as reported in the Supervisory Banking Statistics, from the holdings of unencumbered securities and loans, excluding those vis-à-vis other banks, see Annex B). The selection of potential illustrative assets is illustrative and does not necessarily coincide with the eligibility criteria currently in place. *Option IV.a*: Bank holdings of securities issued by euro area governments and non-financial corporations (NFCs). *Option IV.b*: Holdings of euro area government and NFC securities by sectors other than euro area MFIs, including non-residents. Options IV.a and IV.b do not consider issuer limits currently applied to APP purchases.

3.1.3 The role of frictions and constraints in the adjustment process

The stylised balance sheet analysis corroborates results in the literature that in a completely frictionless economy, the introduction of a digital euro would be neutral for banks' intermediation capacity.[26] From an accounting point of view, this is predicated on the fact that to put digital euro into circulation, the Eurosystem's balance sheet will also adjust, preventing the emergence of a funding gap. With perfect interbank markets, this result extends from the aggregate to the individual bank level, as banks that find themselves in the need to borrow excess reserves to meet their customers' demand for digital euro would not face any restrictions to obtain liquidity from other banks.

However, the presence of constraints and frictions, such as collateral requirements or liquidity regulation, modifies this outcome. For instance, based on the regularities observed over the past decade, a reduction in excess liquidity coupled with an increase in interbank borrowing (Option *II*) is likely to lead to higher interest rates in the money market because banks that are short in reserves are typically also facing higher risk premia. A lack of perfect substitutability between

[26] See Brunnermeier and Niepelt (2019); Kumhof and Noone (2021).

banks' funding sources, e.g. if the conditions of Eurosystem borrowing (Option *III*) do not fully replicate those of bank deposits, may also affect bank funding costs. Frictions and constraints linked to an increased level of Eurosystem borrowing (e.g. stigma[27], collateral scarcity[28] or binding liquidity regulation) may affect banks' willingness to supply credit. General equilibrium effects should also be considered.[29]

At the same time, not all departures from the frictionless economy may cause a negative impact on banks' intermediation capacity; some may contain it. For instance, depositors' responses to the risk-return trade-off of deposits would decrease the substitutability between retail deposits and the digital euro (**Chart 6**). A digital euro offers to some extent similar services to retail deposits but with a lower risk. Yet, for the same reason insured deposits, especially if backed by strong sovereigns, may be less sensitive to substitution into digital euro in normal times.[30] As for uninsured deposits, interest rates earned by depositors generally already reflect inherent bank-specific risks. Therefore, a positive remuneration of deposits, capturing the relevant risk-return trade-off, can be expected to make those deposits less prone to substitution than what might be suggested by aggregate figures.[31] Additional stickiness in deposits may derive from relationship lending, whereby depositors would be more hesitant to terminate a deposit account with a bank with which they may also maintain a credit relation.[32]

27 Unless central bank funding is priced competitively, markets could perceive participation at central bank liquidity-providing operations as signalling liquidity constraints, thus leading to stigma. Stigma could thus hamper the replacement of lost deposits with central bank borrowing, especially for those banks most in need of this adjustment option.

28 By construction, the recourse to central bank funding is conditional on the availability of assets eligible as collateral. Constrained banks could then favour the acquisition of eligible assets at the expense of granting loans.

29 For instance, any of the outlined adjustment channels would likely have an impact on yields, which – in turn – would depend on the remuneration of the digital euro itself and the general interest rate environment. Channel IV.b provides a clear illustration of this aspect: it implies a reallocation of the private sector's portfolio, which would change demand and supply in the securities market and likely alter yields.

30 The sovereign-bank nexus could become relevant in the context of the introduction of a potential digital euro and could lead to a higher take-up in countries facing higher risk premia.

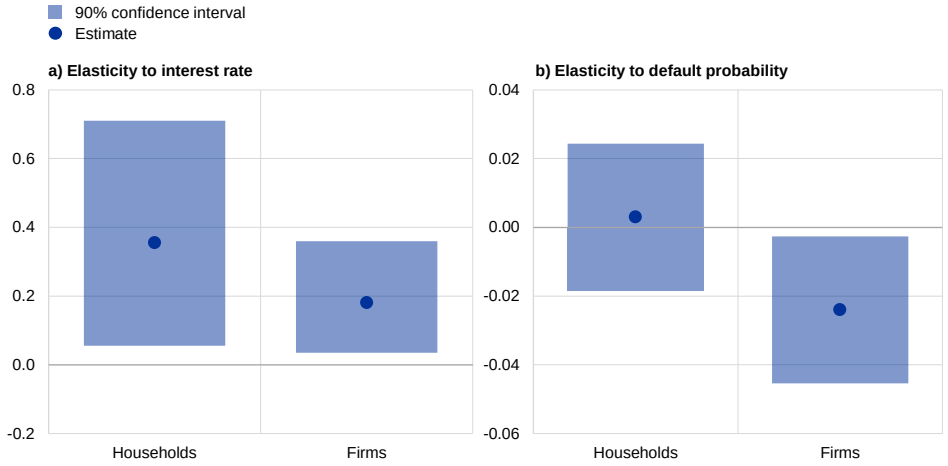
31 Assuming that the remuneration of the digital euro would not significantly exceed the nil one of physical cash.

32 Concerns about substitutability between retail deposits and the digital euro should be extended to the overall funding of banks, including bank bonds. In principle, the same risk of substitution by retail investors away from deposits may apply to bank bonds, again considering the latter's trade-off between remuneration and riskiness.

Chart 6

Elasticity of deposits to deposit rates and banks' default probability

(percentages of a bank's share in the domestic market)



Sources: ECB (individual balance sheet items (iBSI) data) and ECB calculations.
Notes: Diamonds report the coefficient estimated from a IV regression with the (log) share of a given bank in the domestic deposit market as a dependent variable and the deposit rate and the probability of default (computed with a risk neutral model with a constant hazard rate, see Hull (2012)) as explanatory variables. The IV strategy follows Berry (1994) for identification of demand systems, where deposit rate and default probability are instrumented by the bank-specific reactions to monetary policy or sovereign risk, measured by the interactions between bank dummies and the EONIA or the spread between the 10 year sovereign bonds and the EONIA, respectively. The specification includes country-month and bank fixed effects, and controls for bank profitability (ROE), excess liquidity holdings, holdings of securities, deposit ratio and NPL ratio. Shaded areas report 90% confidence intervals with errors clustered at the bank level. Latest observation: May 2021.

Nevertheless, frictions and regulatory constraints are pervasive in the current financial system and need to be accounted for. Consequently, when evaluating the conditions under which a potential introduction of a digital euro could take place, a careful assessment of such frictions and the implications that they would have on banks' funding options is required.

3.2 Simulated bank responses to CBDC demand under liquidity risk preferences and regulation

To meet customer demand for CBDC, individual banks face a trade-off between balancing their profitability and liquidity risks. To exchange retail deposits with CBDC, a bank can either use its own reserves or acquire new reserves via central bank funding, or market funding,[33] in particular repo instruments with a short- (ST), medium- (MT), or long-term (LT) maturity.[34] When choosing between these options, a bank faces a trade-off: secured funding is generally cheaper than unsecured funding[35] and short-term funding is cheaper than long-term funding.

[33] Banks can either receive reserves directly from other banks via interbank lending or by issuing bonds held by other banks. Another possibility for banks to accumulate reserves is to sell assets. Selling an asset has almost the same impact on liquidity risk as using the asset as collateral in secured borrowing with more than one year of maturity. The only difference between the two options is the haircut which is applied to the asset if it is not sold but encumbered. Selling assets is not considered in this exercise for simplicity, which does not alter our conclusions.

[34] A short-term maturity is less than one month, medium-term between one and 12 months, and a long-term maturity exceeds 12 months.

[35] Collateralised funding is cheaper because the lender will receive the collateral in the event of the borrower's default rather than hoping to receive (partial) payment from the insolvency estate.

However, using its own reserves or obtaining funding secured by high quality liquid assets (HQLA) negatively impacts banks' liquidity positions. Drawing down or encumbering its stock of HQLA depletes the pool of assets that can be liquidated in times of need.[36] Furthermore, using short- rather than long-term funding increases roll-over risk in times of stress.

The monetary policy stance prevailing at the time the digital euro is introduced further influences these trade-offs. While acknowledging the uncertainty regarding the future macroeconomic environment and central bank response, the analysis presented here focuses on bank balance sheets and their potential adjustment. The analysis uses bank-specific data regarding the stock of deposits, available collateral, reserves, and liquidity buffers as of Q3 2021 for the euro area's significant institutions and those less significant institutions that report excess reserves, collateral, and liquidity ratios. Abstracting from the current extraordinary central bank response to the pandemic crisis, we assume that the prices of short- and medium-term market funding are above the deposit facility rate and below the main refinancing operations (MRO) rate.[37] The monetary policy stance at the time of CBDC introduction will determine the DFR and MRO rates and conditionalities and influence market prices.

A bank's reaction to CBDC demand is simulated using a constrained optimisation model in which a bank is expected to minimise its funding costs, subject to a number of constraints. First, a liquidity constraint: it is assumed that a bank wants to hold a voluntary buffer above its regulatory requirement which is at least as high as half of its current liquidity buffer.[38] To note, unsecured long-term funding and long-term central bank funding collateralised with non-HQLA, such as additional credit claims (ACCs), do not have a negative impact on liquidity ratios. Second, a collateral constraint: secured funding from the repo market must be secured by HQLA. The collateral constraint does not apply to central bank funding as it can also be secured by non-HQLA collateral such as ACCs. Third, banks face two types of reserve constraints: each bank faces individual reserve constraints and the banking sector as a whole is constrained by the amount of reserves in the system. If a bank uses the reserves borrowed from another bank to meet CBDC demand, the amount of available reserves in the system falls.[39] In the simulation, banks will resort to the cheapest funding option unless they are faced with a constraint. Therefore, banks that are either liquidity or collateral constrained must resort to unsecured or non-HQLA secured funding. In case the current stock of reserves available in the system is insufficient to meet CBDC demand, or in other words when banks cannot obtain sufficient reserves in the interbank market, banks can obtain additional

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36 Naturally, reserves are considered a HQLA. The impact of secured borrowing on liquidity ratios is larger compared to using own reserves as more HQLA is encumbered due to applicable haircuts.

37 It is acknowledged that, depending on market conditions and bank-specific considerations, medium-term funding may be more costly than MROs. This alternative scenario does not affect the main conclusions from this analysis.

38 The liquidity requirements are the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR).

39 Reserves are available as long as there are some banks that are willing to lend part of their excess reserves, i.e. that are above their preferred liquidity ratio and still hold excess reserves.

reserves from the central bank: via MROs if they are not NSFR constrained and via special long-term central bank funding if they are.

The simulation suggests that for low levels of CBDC demand, most banks will be able to meet customers' demand for CBDC by using their own reserves without excessively dipping into their voluntary unencumbered HQLA buffer. Chart 17 shows how the circa 2,000 banks considered in our simulation would accommodate the outflow of different fractions of their overnight deposits from households (HH) and non-financial corporations (NFC). To note, in scenarios A and C introduced in Section 2.1, €180 billion and €647 billion in overnight deposits are expected to be substituted respectively. These scenarios can be roughly compared to a 4% or 8% outflow of individual banks' HH and NFC deposits in our simulation, which sum respectively to about €415 billion and €830 billion. In this case, Chart 17 shows that almost all banks could rely on their own reserves to meet CBDC demand. Still, 2% to 6% of CBDC demand is met using secured short-term funding or unsecured medium-term funding due to individual banks' reserve constraints or liquidity preferences.

To meet high levels of CBDC demand, banks have to rely on central bank funding provided against non-HQLA collateral. The high-demand scenario B introduced in Section 2.1 with an estimated substitution of €6.4 trillion of overnight deposits can be compared to a 60% deposit outflow for individual banks in Chart 7. In this case, only 37% of CBDC demand could be met by using own reserves and 6% by using market funding. As the excess liquidity available in the system is exhausted, banks would need to rely on central bank funding to accommodate the remaining 57% of the high CBDC demand.[40] In particular, 45% of CBDC demand needs to be met using long-term central bank funding secured by non-HQLA so as to allow banks to preserve 50% of their current liquidity buffers. A sensitivity analysis shows that if banks were willing to draw down their reserves to the regulatory requirement (100% LCR and NSFR), still 37% of CBDC demand would need to be met using central bank funding secured by non-HQLA, of which 19% would be long-term central bank funding.

If a digital euro was introduced now in the presence of such high reserves, most banks could accommodate CBDC demand as anticipated in scenarios A and C using their own reserves, under assumed liquidity preferences. A bank balance sheet simulation model suggests that most banks could accommodate CBDC demand using their own reserves with low CBDC demand. However, it suggests that bank-level heterogeneity with respect to liquidity preferences and reserve and collateral availability could result in diverging bank responses to CBDC. Furthermore, liquidity regulation or voluntary liquidity buffers reduce the total amount of reserves that banks are willing to use or sell to facilitate CBDC conversion. Thus, the central bank should be prepared to provide non-HQLA long-term lending (>1

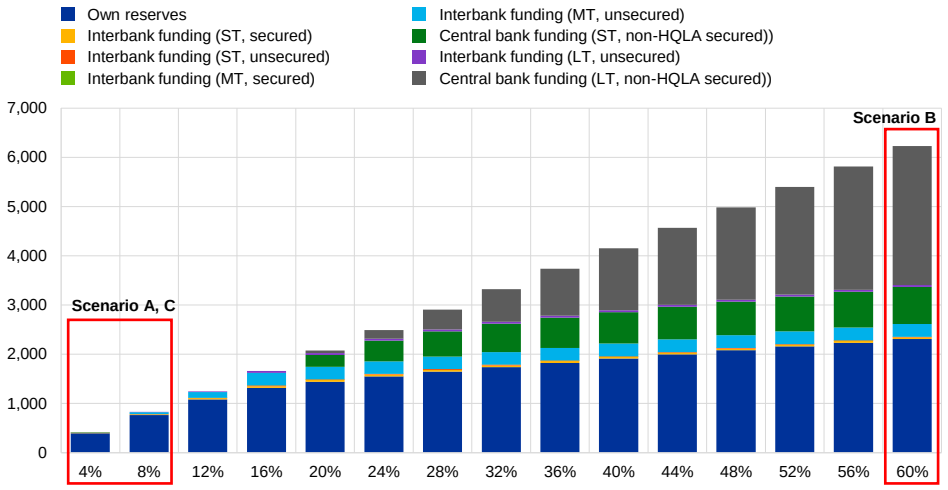
[40] For CBDC demand corresponding to 18% of deposit outflows, the excess liquidity distributed through the interbank market is exhausted. At this point, central bank funding would be needed to meet CBDC demand under the assumption that banks would be willing to use half of their current liquidity buffers. If banks were unwilling to dip into their buffers at all, they would only use long-term central bank funding against non-HQLA collateral to meet any CBDC demand, if available. In contrast, if banks were willing to use their entire liquidity buffer, central bank funding would only be needed if CBDC demands exceeded 30% of relevant deposits.

year) or non-HQLA purchases to ensure that banks do not have to go below their preferred liquidity ratios to meet CBDC demand.

Chart 7

Bank balance sheet re-optimisation

(x-axis: share of deposit outflow covered by funding sources; y-axis: EUR billions)



Source: Own calculations from simulation using regulatory data.
Notes: The simulation uses data from Q3 2021 for a selection of SIs and LSIs.

3.3 Potential impact of a digital euro on bank intermediation capacity and lending conditions: insights from bank valuations

The impact of a digital euro on banks' intermediation capacity, and implicitly their lending conditions, depends on the adjustment in banks' funding and profitability. Effects are likely to be heterogeneous across banks, mirroring, among other things, banks' reliance on deposit funding.[41] If, for example, the potential for deposit disintermediation has a bearing on banks' profitability, this might also have implications for banks' intermediation capacity and, ultimately, lending conditions. At the same time, the introduction of a digital euro – if intermediated through the banking system – could allow banks to develop an additional business area by offering access to and services building on the digital euro, as well as incentives for efficiency gains.[42] This section explores the potential implications for bank

41 On aggregate, euro area retail deposits account for 26% of banks' main liabilities, hovering around historical highs, in part owing to monetary policy measures. A large portion of euro area banks, for which retail deposits account for more than 50% of liabilities, may be more exposed to deposit substitution pressures. Yet, more than 35% of banks in the euro area may benefit from the introduction of a digital euro, through efficiency gains and additional revenue streams, without being seen as exposed to the risks of disintermediation, given the lower share of retail deposits (less than 10%).

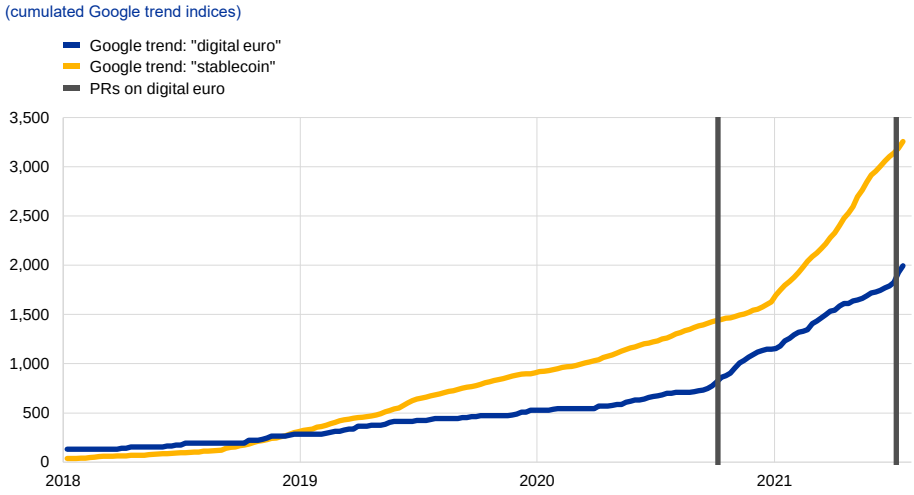
42 The impact on profitability is highly dependent on the prevailing rate constellation – as higher deposit rates make the threat of deposit disintermediation less pressing – and on the amount of excess liquidity in the system at the time of introduction – as in a regime of abundant excess liquidity remunerated below deposits a deposit outflow matched by excess liquidity may generate an outright mechanical increase in net interest margins.

intermediation capacity making use of market reactions to digital euro announcements.

Market participants are likely to have been paying attention to the perceived impact that a digital euro might have on financial markets, and on the profitability of the euro area banking industry. A change in the pace was visible after the publication of the Eurosystem report on the digital euro (ECB, 2020a), and again more recently with the decision to launch the digital euro project on 14 July 2021 (**Chart 8**).

Chart 8

Search interest around stablecoins and digital euro over time



Sources: Google trends and ECB calculations.
Notes: Numbers represent cumulations over time of search interest relative to the highest point of interest between 2016 and the latest observation, and constitute worldwide indices. A search interest of 100 is the peak popularity for the term in a given week. A search interest of 50 means that the term is half as popular than at the peak. A score of 0 means there was not enough data for this term. Latest observation: 23 July 2021.

Bank valuations provide some insight as to what investors currently think a digital euro might entail for banks' business models. To the extent that banks' stock prices reflect also the present discounted value of the future stream of profitability, their changes around events that define agents' expectations about the digital euro, net of a potential change in discount factors, can be a measure of the impact of the digital euro on bank profitability. Since the digital euro project is still under development, stock market developments might be one of the few, however partial, sources of evidence one can look at to gain insights over expectations over the digital euro and its consequences for the euro area banking system.

In order to analyse banks' stock price reactions to news related to the digital euro, the change in overall and bank-specific stock prices is accounted for. In a first step, the reaction of bank stock prices is gauged through the lens of a standard factor model of stock market returns fitted to euro area banks' stock market returns at a daily frequency.[43] A 3-factor Fama-French model is fitted to euro area banks' stock market returns at a daily frequency to identify potentially abnormal

[43] See, as an example of a similar methodology, Borisov, Goldman and Gupta (2016). For the exposition of the 3-factor Fama-French model see Fama and French (1993).

returns around events related to the digital euro, or digital currencies more in general. Returns are classified as abnormal to the extent that they deviate from the returns explained by the regularities captured by Fama-French factors.[44] The sample is based on close to 140 banks from 1 January 2007 to 30 April 2021, and a (continually expanding) series of daily events related to digital euro or stablecoins distributed over the last three years is explored.[45]

Bank characteristics like the reliance on deposit funding can help explain bank-specific stock price reactions around digital euro events. The first step of the analysis allows to characterise potentially abnormal returns of banks around events related to the digital euro or digital currencies. In the second step, the evolution of abnormal returns estimated in the first step is assessed against the type of information that each event carries and the bank characteristics of the cross-section of banks associated with a positive or a negative reaction to CBDC news. Abnormal returns are regressed on bank specific characteristics such as the reliance on deposits, the non-performing loan (NPL) ratio, the RoA, the cost-to-income ratio, the holdings of securities, the excess liquidity holdings, the amount of unused TLTRO borrowing allowance or the relevance of TLTROs in the overall balance sheet, the price-to-book ratio, the market capitalisation or the CDS spread.[46]

Bank stock market valuations for banks relying on deposit funding reacted more strongly to news about the digital euro, with an initial drop followed by a reversal (Chart 9). Following the publication of the ECB report in early October 2020, stock prices more reliant on deposit funding declined but recovered fully as more details about actual design and timing of the project were made public.[47] Stocks reflected the cleavage between banks perceived to be more exposed to the new technological threat, like those relying on deposit funding, and other banks. This reaction is consistent with market participants either discounting a potentially large disintermediation effect or needing several months to absorb the information flow on this subject. The connection between deposit funding and banks' reactions has become particularly intense since then (**Chart 11**, LHS panel). In line with the considerations on the potential positive impact on profitability, related to the potential new business opportunities created by the digital euro, stock prices of banks with low

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44 The model for the first step is as follows: $R_{b,t} = \beta_{m,b}R_{m,t} + \beta_{HML,b}R_{HML,t} + \beta_{SMB,b}R_{SMB,t} + \alpha_b + \gamma_b^{e_1}\delta_t^{e_1} + \cdots + \gamma_b^{e_N}\delta_t^{e_N} + \varepsilon_{b,t}$, where $R_{b,t}$ is the return on the stock of bank b between the day before and the day after t, $R_{m,t}$, $R_{HML,t}$ and $R_{SMB,t}$ are the (excess) market return, the small-minus-big and the high-minus-low factors of the standard Fama-French set-up and $\delta_t^{e_j}$ are dummies that take value 1 if the event e_j takes place in day t. We include a constant α_b. We estimate the model for each bank, which means that all coefficients $\beta_{m,b}$, $\beta_{HML,b}$, $\beta_{SMB,b}$, $\gamma_b^{e_j}$ and α_b are estimated for each bank b.

45 See, for example, https://www.ecb.europa.eu/home/search/html/digital_euro.en.html for a comprehensive list of communications on the digital euro provided by ECB board members, which we complement with news related to the Libra project, among others. As many of these events do not have a precise timing beyond the date in which they took place, the highest frequency at which the exercise can be conducted is daily.

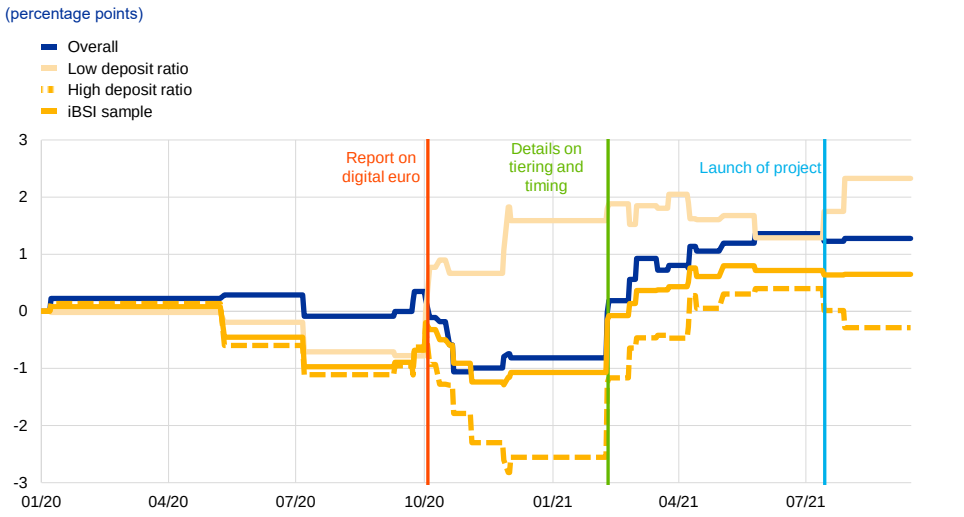
46 The model for the second step is as follows: $\hat{\gamma}_b^{e_j} = \zeta_j + \zeta_b + \xi X_{b,j} + \varepsilon_{b,j}$, where the observation is a given bank b in an event j, $\hat{\gamma}_b^{e_j}$ are the abnormal returns estimated in the first step for each bank b and each event j, $X_{b,j}$ is a set of (pre-existing) bank characteristics. ζ_j and ζ_b capture event- and bank-specific unobserved heterogeneity specific to digital euro or stablecoin events, when warranted. See Burlon, Montes-Galdón, Muñoz and Smets (2022) for details.

47 See, for example, "Evolution or revolution? The impact of a digital euro on the financial system", Speech by Fabio Panetta, Member of the Executive Board of the ECB, at a Bruegel online seminar Frankfurt am Main, 10 February 2021.

reliance on deposits increased in response to digital euro events ever since the publication of the ECB report in October 2020. Interestingly, valuations for smaller banks recorded an upward trajectory since October 2020, consistent with the idea that, ultimately, the digital euro could also be a considerable support towards the digitalisation of the euro area banking sector, levelling the playing field for smaller banks.[48]

Chart 9

Stock market reactions to CBDC news by euro area banks



Source: Burlon, Montes-Galdón, Muñoz and Smets (2022).
Notes: A 3-factor Fama-French model is fitted to daily two-day stock market returns of 134 euro area banks, isolating the abnormal returns occurred at key events for each bank. Each horizontal segment reports the cumulated abnormal returns across key events. The solid dark yellow line focuses on the IBSI sample, with dashed dark yellow and solid light yellow lines reporting the detail by level of deposit ratio, above and below median respectively. The three vertical lines indicate three key noteworthy events: the publication of the ECB report on the digital euro on 2 October 2020, the speech by Mr Panetta on 10 February 2021 (Panetta, 2021b) and the launch of the digital euro project on 14 July 2021. Latest observation: 10 September 2021.

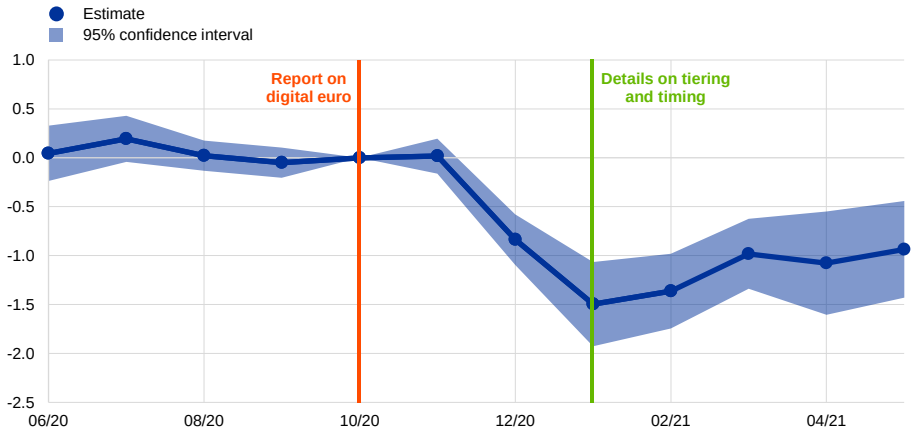
The evolution of valuations seems to point to investors anticipating diverging, but temporary, implications for lending conditions across bank business models (Chart 10). These seem to be perceived by markets as being differentially affected by the introduction of a digital euro, with some poised to benefit, and others to lose. The reallocation in market shares that this differentiated impact might entail can be quantified by studying the reaction of banks themselves in the months spanning the events outlined above (and as measured by the difference between the dotted and dashed yellow lines). Looking at the developments in loan markets using transaction level data and controlling for potentially confounding factors such as loan demand, the cross-sectional difference in the reaction of stock prices to digital euro news (amounting to roughly 4 percentage points) has been associated with a reallocation of market shares of around 1.5% of ex ante volumes at the peak. This reallocation was, in fact, temporary and limited to the period leading up to the communication of further details about the project.

48 See, for example, "Stay safe at the intersection: the confluence of big techs and global stablecoins", speech by Fabio Panetta, Member of the Executive Board of the ECB, at the panel on "Cross-border dimensions of non-bank financial intermediation: what are the priorities for building resilience globally?", as part of the UK G7 Presidency Conference on "Safe Openness in Global Trade and Finance" hosted by the Bank of England, 8 October 2021.

Chart 10

Change in loan volumes to firms associated with a 4% cumulated gap in bank stock prices

(percentages of ex-ante volumes)



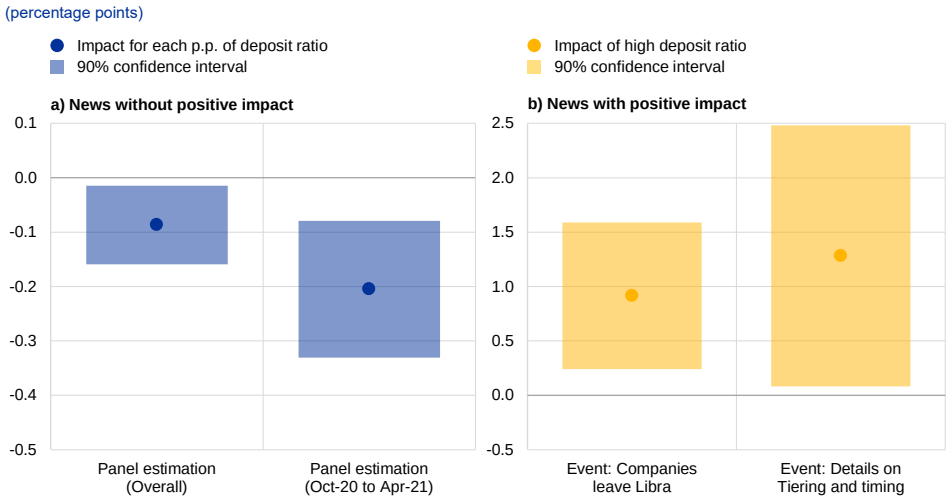
Source: Burlon, Montes-Galdón, Muñoz and Smets (2022).
Notes: Diamonds report coefficients of a diff-in-diff set-up where the growth rate of loan volume from October 2020 to each horizon indicated on the horizontal axis is regressed on the stock price reactions to digital euro events as of October 2020. The specification includes firm fixed effects à la Degryse et al. (2019) and (lagged) bank-level controls. The blue area reports the 95% confidence interval based on standard errors clustered at the bank level. Coefficients rescaled by valuation gap cumulated until February 2021. End-of-month data.

Reactions to news are not confined to digital euro-related events but mirror also developments in the broader ecosystem of stablecoins, suggesting that markets may be discounting a counterfactual scenario for the absence of a digital euro where the void is filled by alternative digital currencies. The counterfactual for the impact of the digital euro on banks' valuations might not be a world without any CBDCs or stablecoins, but rather one where banks' business models are threatened by the availability of these assets and the rise of new actors, like Big Tech companies, with ex-ante competitive advantages in responding to new forms of demand for digital currencies and cryptoassets. Accordingly, valuations of banks relying heavily on deposit funding also respond to news about stablecoins more broadly. For example, the abnormal (positive) returns observed on 11 October 2019 and 10 February 2021 depended similarly on the reliance on deposit funding (**Chart 11**, right panel). While the second event squarely referred to the digital euro, when potential details about the project in terms of the threshold of the tiering system (€3,000 per user) and the timing of the project (four to five years) were communicated to the public, the first event was connected to stablecoins more

broadly, when eBay, Mastercard, Stripe, Visa and Mercado Pago all left the Libra project, following PayPal's departure one week earlier.[49]

Chart 11

Impact of deposit funding on market reactions to Libra- and digital euro-related news



Sources: ECB website, Dealogic and ECB calculations.
Notes: Diamonds report the results of regressions where the abnormal returns on euro area banks' stocks around digital events is regressed on the deposit ratio of each bank. Shaded areas report the 90% confidence intervals. LHS panel includes event and bank fixed effects, and controls for NPL ratios, ROA, cost-to-Income ratios, shares of securities and excess liquidity holdings over assets, reliance on and availability of TLTROs, price to book ratios, market capitalisation, and CDS spreads. The RHS panel regresses the abnormal returns in two key events on a dummy that takes value 1 if a bank has a ratio of deposits over main liabilities above the median value. The two events mentioned on the RHS panel happened on 11 October 2019 and 10 February 2021.
Latest observation: 30 April 2021.

The estimated stock market reactions are suggestive of perceived implications for bank funding and profitability, although the role of central bank balance sheet is unlikely to be factored in yet. The actual impact of the introduction of the digital euro on banks' balance sheets will depend on the evolution of the balance sheet of the central bank as well. This is because the central bank can react to the potential increase in liabilities induced by the increased demand for digital currency by either accepting to compress its other liabilities or by expanding its assets. On the one hand, the difference in reactions between banks that rely on deposit funding and other banks does suggest a link with the perceived value of the deposit franchise. On the other hand, the reaction of bank market valuations to digital news might not fully discount these mechanics, as they are arguably a form of externality via the central bank reaction function or the wider customer base of banks' depositors that agents

[49] These early considerations on the perceived impact of the digital euro on banks' future profitability are subject to some uncertainty. First, it might still be difficult for market participants to gauge the potential relevance that a digital euro might have on banks' business models. Second, the model used to isolate abnormal returns from otherwise normal fluctuations of banks' stock prices, however standard, may be misspecified. Third, the period under consideration for quantifying the abnormal returns might also be special, in light of the chronically low price-to-book ratios over the past 5–10 years and the extraordinary environment to have emerged from the pandemic. Fourth, there may be concomitant events that increase the measurement error of single events. The current approach partially addresses these concerns with a long time period running from 2007 and robustness checks in the most recent part of the sample, considering a wide set of events (34 in total) referring to digital euro but also to other stablecoins that should average out the potential misrepresentation of single events, with both positive and negative news in terms of their likely impact on stock market valuations. Further robustness is offered by additional analysis of simple bank stocks' betas, whereby high-deposit banks show higher volatility than low-deposit banks in the period between October 2020 and February 2021. Nonetheless, given that evidence on the implications of a digital euro is still scant, a residual degree of caution is warranted at this stage.

are unlikely to factor in, akin to banks' stock price reactions to NIRP cuts or increases in asset purchases.

4 Considerations on the severity of potential economy-wide bank runs

Besides any implications for bank intermediation in normal times, a digital euro could affect the severity of bank runs as it would provide citizens with a super-safe asset at comparatively low storage costs. Large scale withdrawals of insured bank deposits have recurrently occurred in the past (Iyer and Puri, 2012; Brown et al., 2020). During times of stress and depending on its design, the role a digital euro could potentially play as a store of value could become particularly relevant as it is a more easily accessible super-safe asset with lower storage costs, when compared to cash (Panetta, 2021c). Thus, some authors have suggested that CBDC may "open a highway to bank runs" (Callesen, 2017) and that "deposits would more readily migrate to the CBDC during times of stress" (Broadbent, 2016).

Two models are used to discuss the possible consequences a digital euro could have for the severity of system-wide bank runs. First, a model for simulated bank runs is applied to past economy-wide bank run episodes to assess what would have happened had a digital euro coexisted with cash. Simulations under different limits on CBDC usage or remuneration are performed.[50] Second, based on an extension of the Diamond and Dybvig (1983) model that incorporates cash and CBDC, the paper explores additional possible implications such as the impact CBDC could have on welfare in the event of a system-wide bank run.

The proposed set-ups share characteristics that make them appropriate to consider the severity of system-wide bank runs. First, both set-ups consider that individuals can convert their bank money either into cash or into CBDC.[51] Second, central bank liabilities are only used as a store of value and CBDC is generally preferred due to a technological superiority. Third, both models allow us to assess the impact a digital euro may theoretically have on the severity of bank runs along at least one of the two dimensions: (i) the scale of a bank run, understood as the share of total bank deposits that is withdrawn during a bank run; and (ii) the speed at which a bank run occurs, defined as the time it takes for a certain share of bank deposits to be withdrawn.[52] Fourth, the study focuses on the potential consequences for

50 See Panetta (2021a) for proposed measures to prevent an excessive flow of funds into CBDC.

51 In the case of a bank run, the uncertainty about the right counterfactual is notably more limited (when compared to the analysis of the impact in normal times) as other forms of digital money (i.e. stablecoins) are unlikely to compete with a digital central bank liability as a store of value.

52 Although it goes beyond the scope of this paper, there is a third important dimension along which a CBDC could affect the severity of a system-wide bank run, namely its likelihood. One of the possible options for extending this analysis in order to address this issue would be to extend the model proposed in Muñoz and Soons (2022) to endogenise the probability of system-wide bank runs following the approach by Goldstein and Pauzner (2005).

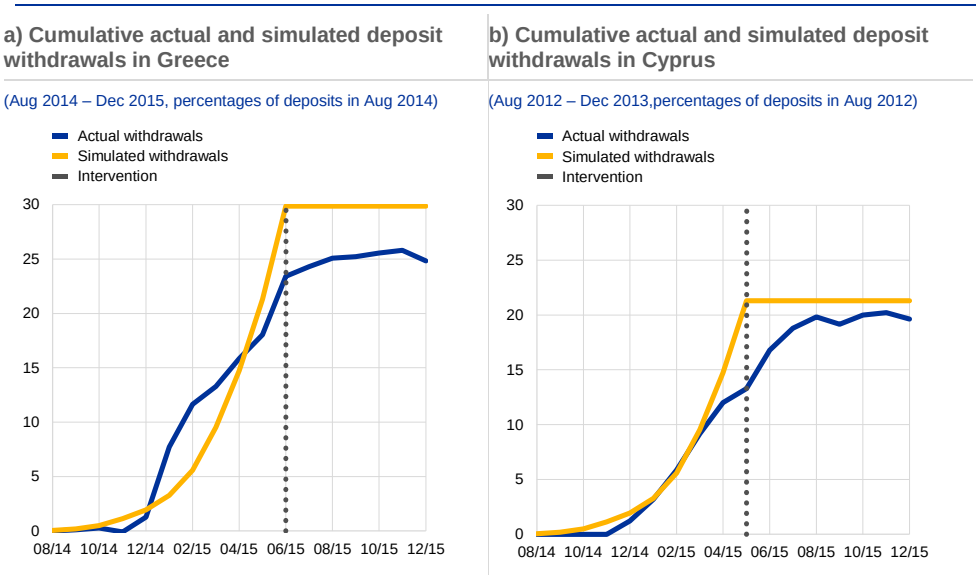
economy-wide bank runs, disregarding the effects a CBDC may have on individual bank run dynamics.[53]

4.1 Insights gained from a model for simulated bank runs

Models can be used to simulate bank runs that approximate the speed and scale of past economy-wide bank runs. Individuals are assumed to withdraw their deposits when their expected return from holding cash and/or CBDC exceeds that of deposits.[54] The dynamics of monthly deposit withdrawals are simulated, and the parameters of the model are calibrated such that the simulated withdrawals match the deposit outflows registered during the recent economy-wide bank runs in Greece (2015) and Cyprus (2013). **Chart 12** shows that the simulated bank runs approximately match the speed and scale of both nationwide bank runs.[55]

Chart 12

Deposit withdrawals in Greece and Cyprus



Source: Own calculations from simulation using BSI data
Notes: The dotted grey line refers to the actual date at which the corresponding national public authorities adopted bank holiday measures.

Counterfactual simulations that vary the limits on CBDC usage and remuneration are used to describe the potential impact of a digital euro on the speed and scale of bank runs. The introduction of a digital euro affects the expected return maximisation of depositors in two ways. First, depending on the selection and calibration of usage limits and remuneration, a digital euro may allow for a lower-cost alternative to cash holdings, and it may also allow for "unlimited"

53 Some authors have suggested that the introduction of CBDC will mostly affect system-wide bank runs as opposed to single-bank bank runs since it is already possible to digitally and instantly transfer money between banks (Kumhof and Noone, 2021). This view is supported by the evidence on bank deposit flows reported in Rainone (2021).

54 See Box 4 for further details on the assumptions and specification of the model.

55 The remainder of the illustrative exercise is based on the Greek case.

withdrawals.[56] Second, and based on the illustrative digital euro take-ups considered in Section 2.2., it is assumed that each citizen substitutes some of her overnight deposits for digital euro holdings before the bank run starts (i.e. substitution in normal times). That is, once the bank run has been triggered, the larger the conversion of deposits into digital euro prior to the run is, the lower the expected scale of the run will be.

If demand is unconstrained, a digital euro would lead to an increase in the scale and speed of a (simulated) system-wide bank run.[57] When compared to the no digital euro scenario, the increased scale of bank runs under illustrative take-up scenarios A and B is reflected by a larger share of deposit withdrawals at intervention, while the increased speed of bank runs is reflected by the shorter time it takes to reach a certain amount of deposit withdrawals (Chart 13).[58] The scale and speed of simulated bank runs is more pronounced under CBDC, since this central bank liability is assumed to be subject neither to storage costs nor to a convertibility limit.[59] When compared to take-up scenario B, the scale and speed of simulated bank runs are larger under take-up scenario A, as it entails a smaller substitution from bank deposits into digital euro before the bank run occurs (€500 and €7,500 respectively).[60] This reveals a trade-off: the lower the demand for CBDC in normal times is (i.e. prior to the bank run), the larger the level of aggregate deposits that can potentially be withdrawn in times of crisis.

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56 It is assumed that digital euro holdings are free of service charge, so digital euro holdings are costly only if the rate at which they are remunerated is negative. The paper refers to “unlimited” withdrawals in the sense that, in the absence of a convertibility limit on digital euro, individuals could potentially withdraw all their deposits thanks to the CBDC.

57 When the capped take-up as specified in Section 2.2 includes a soft limit, it is equivalent to the tiered remuneration scheme as proposed by Bindseil (2020) and Bindseil and Panetta (2020).

58 The potential costs to society of this increased scale and speed of simulated bank runs would need to be weighted with potential benefits that are not considered in the analysis, For instance, with a digital euro the potential a system-wide bank run would have for altering the well-functioning of the payments system and for being disruptive in this regard may significantly decrease. That is, with a digital euro economy-wide bank runs may actually be less costly to society.

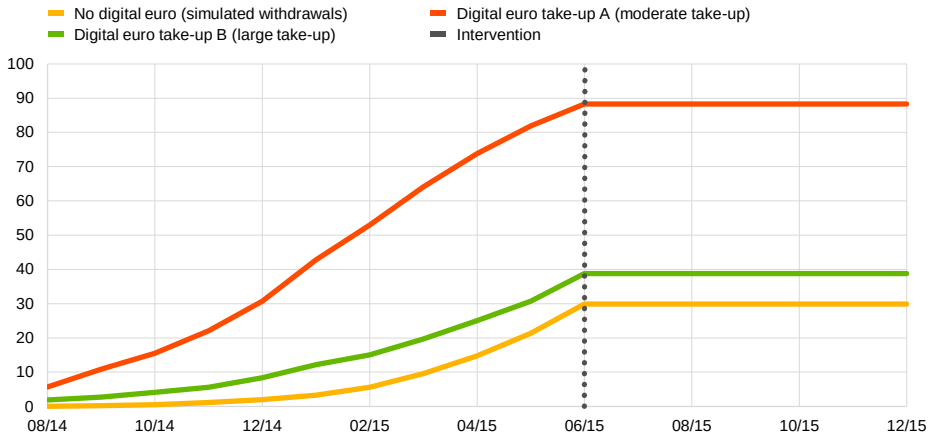
59 Note that the simulated bank run that is taken as the reference scenario (no digital euro case) should be interpreted as an adverse baseline scenario since, given the banking reforms that have been implemented over the last decade, the likelihood of having a system-wide bank run of this magnitude has decreased.

60 In the illustrative take-up scenario B discussed in Section 2.2., households demand €3.1 trillion digital euro of which €2.6 trillion is substituted from overnight deposit holdings. Dividing the total deposit substitution by 342 million citizens results in an approximate per person substitution of €7,500. A similar calculation is applied to the moderate digital euro take-up scenario A. Note that these demand scenarios are subject to high uncertainty (see Section 2).

Chart 13

Simulated cumulative deposit withdrawals in Greece under illustrative digital euro take-up scenarios A and B

(Aug 2014 – Dec 2015, percentages of deposits in Aug 2014)



Source: Own calculations from simulation using BSI data.

Depending on its calibration, a hard limit on individual CBDC holdings would permit that a digital euro would not amplify the scale and speed of simulated economy-wide bank runs.[61] As shown in panel a) of Chart 14, a €3,000 hard limit on individual digital euro holdings under scenario C would more than compensate any negative impact a digital euro could potentially have on the scale and speed of simulated economy-wide bank runs. This is so, because the demand for a digital euro in normal times (i.e. prior to the bank run) is such that the aggregate level of available deposits that can be withdrawn in the event of an economy-wide run is lower than under the no digital euro scenario. As indicated by the dashed lines, as the hard limit allows for larger holdings of digital euro, the scale and speed of the simulated bank run increases.[62]

If the limit on individual holdings is soft, instead, its effectiveness will depend not only on the calibration of the limit but also on the interest rate at which tier 2 digital euro holdings are remunerated. Panel b) shows that the lower the interest rate on tier 2 holdings is, the more effective the €3,000 soft limit is in neutralising the potential adverse impact of a digital euro on the severity of simulated system-wide bank runs.[63] Provided that the rate at which tier 2 CBDC holdings are remunerated is sufficiently low, changes in the level of the soft limit on individual

61 Under a hard limit on digital euro individual holdings, holdings of CBDC are remunerated at a 0% annual interest rate and beyond that threshold no additional holdings are allowed. In contrast, under the soft version of this limit, holdings beyond that threshold are also allowed but at a dissuasive – possibly negative – interest rate (see Bindseil, 200; Bindseil and Panetta, 2020 for a discussion of the latter, also regarded as a two-tiered CBDC remuneration scheme).

62 Note that, under scenario C, the digital euro take-up in normal times is €3,000 by assumption, which means that even if the hard limit on individual holdings is above €3,000, the take-up will still be the same and, thus, the limit will not be binding in normal times.

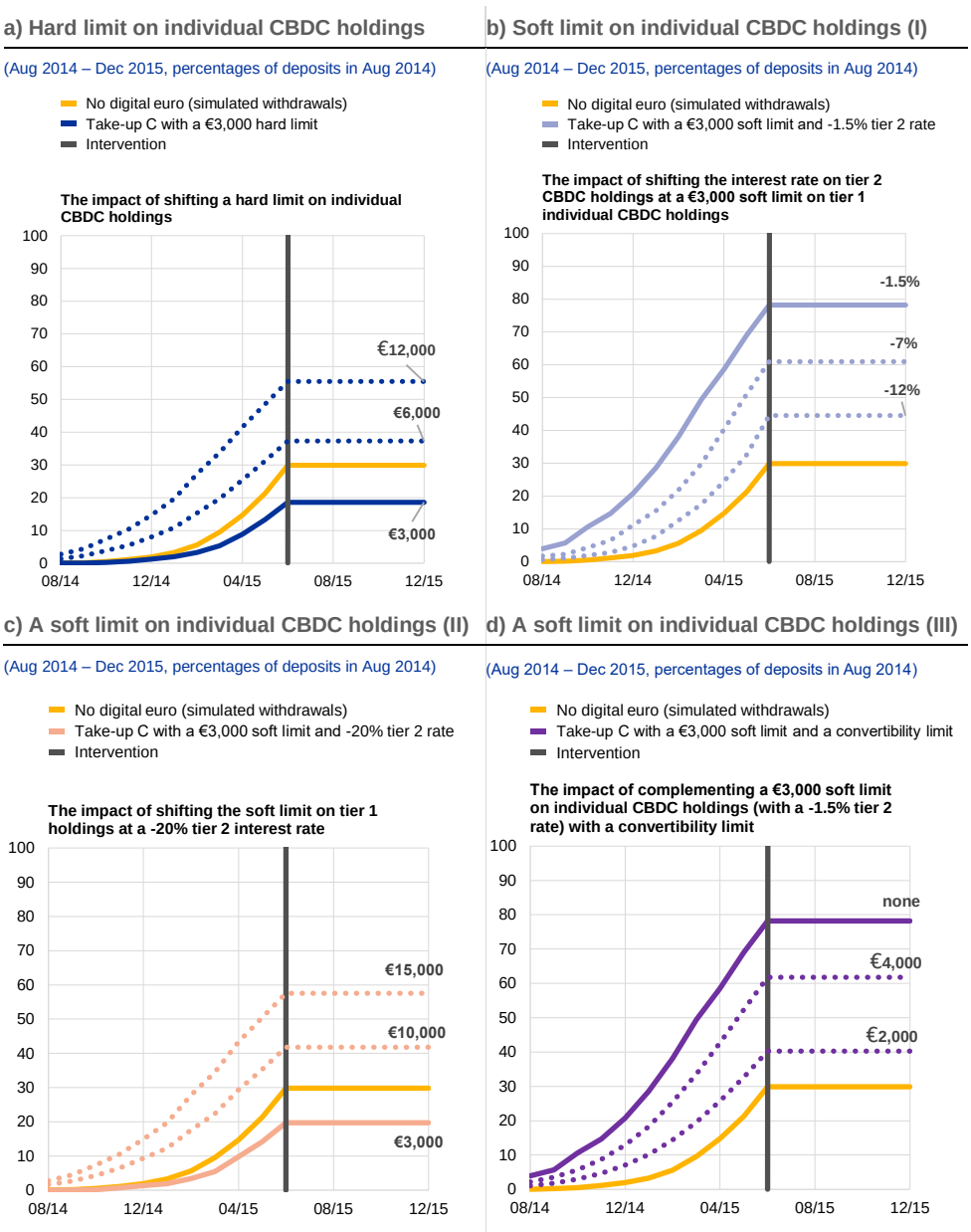
63 As in Bindseil and Panetta (2020), the value that can be taken by the annual rate at which tier 2 CBDC holdings are assumed to be remunerated is assumed to depend on the level of the deposit facility rate. In this case, and for illustrative purposes, the exercise assumes that in the reference soft limit case, this rate is equal to -1.5%. That is, 1% lower than the level at which the deposit facility rate currently stands.

holdings can also have a material impact on the scale and speed of economy-wide bank runs (panel c).

A limit on CBDC convertibility can complement limits on individual holdings to prevent the introduction of a digital euro from having an adverse impact on the severity of bank runs. Past economy-wide bank runs show that there is often a stage of the episode in which authorities decide to intervene in order to suspend the convertibility of bank deposits into cash or other liquid assets (i.e. bank holiday). In a similar way, a limit on individual holdings (affecting the stock of digital euro) could be complemented by a limit on convertibility of deposits into CBDC (which affects digital euro flows). Panel d) of Chart 14 plots, for the same €3,000 soft limit with a -1.5% annual interest rate on tier 2 holdings, a simulated economy-wide bank run under different CBDC convertibility limits.

Chart 14

Simulated cumulative deposit withdrawals in Greece under illustrative digital euro take-up scenario C: Hard vs soft limits on individual digital euro holdings



Source: Own calculations from simulation using BSI data

Box 1

Model for simulated bank runs: assumptions and estimation

The model considers the euro area population and assumes that each individual holds deposits equal to the average deposit holdings in the euro area in March 2020. In each period, an individual withdraws her deposits when her expected return from holding cash and/or digital euro exceeds her expected return on deposits.

Converting deposits into cash is subject to storage costs and opportunity costs. The opportunity cost of physically withdrawing bank deposits is approximated by the estimated time it takes to withdraw cash multiplied by the average after tax hourly earnings, as suggested by Deutsche Bundesbank (2014). The assumed ATM travel and queuing time during a system-wide bank run is based on the ATM queuing times reported in Greece in 2015. Additional ATM fees are assumed to be zero, and a €10,000 monthly cash withdrawal limit during a system-wide bank run is assumed, motivated by the daily withdrawal limits in Cyprus in 2013 and in Greece in 2015. Finally, the fixed storage cost, a proxy for the loss of banknotes, theft, and other storage costs, is assumed to be 1% of total deposit holdings, roughly based on various suggested magnitudes (Rogoff, 2017; Financial Times, 2015, 2016).

The model implicitly assumes that a system-wide bank run will inevitably happen as the perceived probability of bank default is equal across individuals and linearly increases over time. The benefits of withdrawing bank deposits at any time comprise a common component and an individual component. The common component equals the avoided expected losses on bank deposits, which is determined by the exogenous bank default probability and individuals' bank deposits. The idiosyncratic component is specific to each citizen, is assumed to be normally distributed, and can be interpreted as the different degree of patience each individual has when waiting until deciding to withdraw her deposits. The mean and standard deviation of the normal distribution of the idiosyncratic component are calibrated so that simulated withdrawal dynamics match empirical withdrawals, as shown in **Chart 12**.

To summarise, each individual's cash withdrawal decision $r(\gamma_i) \epsilon \{0,1\}$ is formally determined as

$$r(\gamma) = \begin{cases} 1 \; if \; p \; x \; D + \gamma_i > T \; x \; W + S \\ \\ 0 \; else \end{cases}$$

where $r = 1$ means the person withdraws her deposits as cash, p equals the probability of bank default, D equals individual deposit holdings, $\gamma_i \sim N(\mu, \sigma)$ equals the individual run benefit, T equals the time it takes to withdraw bank deposits, W equals the net hourly earnings and S equals the cash storage cost. This set-up implies that, all other things being equal, only individuals with a sufficiently high idiosyncratic run benefit withdraw their bank deposits.

4.2 Discussion based on a model of panic-based bank runs[64]

The previous analysis is complemented by introducing CBDC and cash in a well-known panic-based bank run model. The Diamond and Dybvig (1983) framework complements the previous analysis by assessing how the introduction of a CBDC affects structural bank intermediation and the scale of system-wide bank runs from a theoretical perspective. In this set-up, system-wide bank runs occur due

[64] The discussion presented in this subsection is based on the model presented in Muñoz, M. A., and Soons, O. (2022), "In search for safety: insured deposits, cash or central bank digital currency?", forthcoming at the ECB Working Paper Series.

to a coordination problem in an environment in which depositors' decision to withdraw can depend on what they believe others will do. If depositors believe others will withdraw, they will also withdraw their deposits, which may ultimately lead to a panic-based economy-wide bank run. The discussion is based on a modification of the original set-up that introduces cash and CBDC in the model and underscores the role of central bank liabilities as safe assets (see Muñoz and Soons 2022).[65]

The introduction of CBDC does not affect the scale of economy-wide bank runs although welfare implications may differ depending on whether CBDC supply is constrained or not. In the event of a panic-based system-wide bank run, the scale of the run remains unchanged as depositors' decision to withdraw their bank deposits depends on what they believe others will do and not on the availability of an additional safe asset.[66] However the welfare implications will vary depending on whether the supply of CBDC is constrained or not due to the key assumption that holding CBDC is less costly – when compared to cash – due to its technological superiority.[67] If the supply of CBDC is unconstrained, welfare losses suffered by those depositors who cannot be fully repaid during a system-wide bank run are lower since, due to the "saved" cash storage costs, the resources available to repay the average depositor upon liquidation are higher. However, in the extreme case that the CBDC remuneration rate is negative and sufficiently low – to the point that holding CBDC is less profitable than holding cash – there would be no demand for CBDC. Similarly, the lower a binding limit on individual CBDC holdings is, the lower the actual CBDC take-up will be and the closer the economy will be, in terms of welfare losses, to the case in which there is no CBDC.

In this model economy, the introduction of CBDC may lead to structural bank intermediation and economic efficiency gains. Outside a system-wide bank run episode and due to its technological superiority, if the supply of CBDC is unconstrained, holdings of this digital central bank liability at least partially replace cash holdings.[68] When compared to the only cash case, and due to the technological superiority of CBDC (which translates into "saved" cash storage costs), available resources of money holders increase. That leads to an increase in bank deposit holdings as well as in banks' holdings of short- and long-term assets (i.e. structural bank intermediation). Restricting or disincentivising CBDC holdings beyond the level that CBDC money holders would optimally like to hold under the unconstrained CBDC scenario would mitigate this "structural bank intermediation effect" and the corresponding welfare gains.

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65 See box 3 for further details on the specification of the model and for a brief summary of the strand of the literature (on CBDC in the Diamond and Dybvig model) this extension contributes to.

66 The scale of a bank run is defined as the share of total bank deposits that is withdrawn during a bank run. This relative measure of the scale of a bank run is unchanged in the model, although absolute deposit withdrawals increase as total bank deposits increase due to CBDC.

67 This feature of CBDC is modelled by assuming that storage costs of cash relative to those of CBDC are positive. Storage costs of cash are assumed to increase with holdings while CBDC storage costs are normalised to zero.

68 The extent to which cash holdings are replaced by CBDC depends on the extent to which CBDC is technologically superior to cash.

Box 2

The Diamond and Dybvig set-up with CBDC

The seminal model by Diamond and Dybvig (1983) simultaneously provides a rationale for maturity transformation by banks (long-term lending funded by short-term debt), for system-wide bank runs and for deposit insurance. A recent strand of the literature introduces CBDC in a Diamond and Dybvig type of model to study the potential consequences of central bank digital currencies for bank intermediation and bank runs. For instance, Keister and Monnet (2020) find that CBDC may improve financial stability as it can provide a central bank with real time about deposit outflows during bank runs and that a low CBDC interest rate may eliminate bank runs. Fernández-Villaverde et al. (2021) show that if the central bank can somehow invest in long-term (risky) assets, CBDC may fully replace bank deposits, since the central bank can provide a comparatively more attractive deposit contract compared to a commercial bank.

Yet, the existing modifications omit certain elements that are crucial to study the potential impact of CBDC as a store of value on the severity of bank runs: i) the central bank's risk management strategy, ii) the provision of cash by central banks, and iii) the provision of bank deposit insurance coverage by the public authorities. Muñoz and Soons (2022) modify the Diamond and Dybvig (1983) model by incorporating these aspects in order to study the demand for CBDC as a super-safe asset, both during bank runs and outside stressed times. The specification of investor demand for safety follows recent literature (Ahnert and Perotti, 2021 and Stein, 2012).

In Muñoz and Soons (2022) individuals have a demand for safe assets which they can satisfy with insured deposits, cash, or CBDC. CBDC is assumed to have lower storage costs compared to cash, so an unconstrained CBDC would at least partially substitute for cash holdings. CBDC does not substitute for bank deposits as banks can offer a higher return on deposits compared to a central bank subject to a risk management policy. On the contrary, individuals increase bank deposit holdings proportionally to the resources they save due to lower storage costs. As in the literature, depositors may panic, resulting in a system-wide bank run, whose scale is independent from the availability of CBDC and does only depend on individuals' beliefs of what others will do. In that case banks are liquidated, but the liquidation value of banks is higher under an unconstrained CBDC due to the increase in bank deposits.

There is a well-established literature that allows for an extension of the Diamond and Dybvig model with CBDC and cash to account for: (i) various options for policy intervention such as deposit freezes (Ennis and Keister, 2009), bank bailouts (Keister, 2016), and central bank intervention as the lender of last resort (Allen et al., 2014); and (iii) the endogenisation of the probability of panic-based runs (Goldstein and Pauzner, 2005). Importantly, under the assumptions made in Muñoz and Soons (2022), CBDC could potentially lead to an increased probability of bank runs since withdrawing deposits would become relatively more attractive (i.e. less costly), when compared with an only cash economy. In that case, a CBDC as a store of value could introduce a trade-off between increased efficiency and higher probability of systemic bank runs.

5 Conclusion

In July 2021, the Eurosystem announced the launch of a project to explore the case for a digital euro and consider its potential design. A digital euro would offer several economic benefits but, depending on its design, could prompt changes in the demand for bank deposits, in turn affecting financial stability and monetary policy transmission. Specifically, reduced demand for bank deposits could have consequences for banking sector credit provision, risk-taking, profitability and resilience. To investigate these and other implications of CBDCs, the Eurosystem has recently launched a multi-year digital euro project aimed at ensuring that the ECB is ready to issue a CBDC if needed.

To address the sizeable uncertainty, this paper develops illustrative take-up scenarios and explains the balance sheet mechanics through which the digital euro would be introduced. Advanced economies do not have experience with CBDCs. For the particular case of a digital euro, anticipating its take-up is particularly challenging as there is a high degree of uncertainty surrounding its demand, many of its design features, and the environment that would prevail by the time it is issued. A stylised balance sheet approach allows the identification of the four different adjustment channels that the banking sector can follow when a digital euro is put into circulation: these include a reduction in banknotes, in excess reserves, liquidity providing operations by the central bank via refinancing operations or purchases.

If markets were perfectly competitive and there were no constraints, a digital euro would not be expected to alter the intermediation capacity of banks. A stylised balance sheet perspective shows that, in the absence of market imperfections as well as regulatory and collateral constraints, a digital euro would not affect the capacity of banks to intermediate funds. Instead, it would trigger an offsetting liquidity operation by the central bank to ensure that the economy-wide liquidity situation is kept unchanged.

Analyses based on bank-level data show that a digital euro can affect bank intermediation if imperfections and constraints surface. Euro area bank-level data reveal that in the presence of imperfections and constraints, such as regulatory and collateral constraints, a digital euro may affect bank funding structures and in turn their intermediation capacity. Furthermore, individual responses to the introduction of a digital euro may significantly vary because of institution-level specificities including, for example, different business models, deposit ratios and funding structures.

The potential impact of a digital euro on economy-wide bank run dynamics depends on usage limits and remuneration, among other factors. A model for simulated bank runs shows that, under an unconstrained CBDC, the scale and speed of bank runs can increase. Instead, if the supply of CBDC is constrained, a CBDC may in fact decrease the scale and speed of runs, when compared to the scenario with no digital euro and depending on the calibration of usage limits and/or remuneration. An extension of the Diamond and Dybvig (1983) model that allows for

CBDC and cash holdings shows that the scale of system-wide runs is not affected by CBDC, although welfare losses experienced during these episodes depend on the selection and calibration of CBDC usage limits and remuneration.

The studies presented in this paper intend to inform the debate on a digital euro at an early stage. As such, these initial findings will be reassessed and updated when more details on the design of a potential digital euro become available. Further extensions could consider that a digital euro may have consequences not only for the scale and speed of bank runs but also for the probability that these events might occur. Finally, the issuance of a digital euro will require careful analyses and discussions on its potential implications for current banking regulation, an aspect not covered in this paper.

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Annex: Balance sheets of the main euro area institutional sectors

Table A

Aggregate positions by sector

Eurosystem

(outstanding amounts in EUR tn)

Assets			*Liabilities*
Gov and PS debt securities	4.1	1.5	Banknotes
Lending to Banks	2.3	4.5	Banks' reserves
Bank debt securities	0.5	0.8	Deposits by other residents
Foreign assets	1.4	0.7	Liabilities vis-à-vis non-residents
		0.8	Capital and reserves
TOTAL	8.3	8.3	TOTAL

Bank

(outstanding amounts in EUR tn)

Assets			*Liabilities*
Loans to households	6.3	8.6	€ Overnight deposits by the PS
Loans to NFCs	4.8	5.2	€ Savings deposits by the PS
NFC securities (debt+equity)	0.4	1.9	€ deposits by non-residents
Credit to government	2.7	2.3	Non-€ deps (incl. non-resid)
Credit to non-banks	2.2	3.8	Debt secuties issued (net)
Foreign assets	5.3	2.6	Capital
Interbank positions	6.6	6.6	Interbank positions
Reserves with Eurosystem	4.5	2.3	Borrowing from Eurosystem
Other assets	0.6		
TOTAL	33.3	33.3	TOTAL

Money market funks (MMFs)

(outstanding amounts in EUR tn)

Assets			*Liabilities*
Bank debt	0.3	0.6	MMF shares
Bank deposits	0.2		
Other resident debt securities	0.2		
Foreign assets	0.7	0.7	MMF shares by non-residents
Other assets	0.0	0.6	
TOTAL	1.3	1.3	TOTAL

Non-banks

(outstanding amounts in EUR tn)

Assets			*Liabilities*
€ Overnight deposits	0.9	10.0	**Insurance & pension schemes**
€ Savings deposits	1.3	15.5	**Investment fund shares**
Loans	6.2	6.3	**Bank and other loans**
Securities and equity	37.7	15.8	**Securities and equity**
Other assets	1.6		
TOTAL	**47.6**	**47.6**	**TOTAL**

Households

(outstanding amounts in EUR tn)

Assets			*Liabilities*
Banknotes and coins	0.8	6.3	**Bank loans**
€ Overnight deposits	5.2	1.0	**Other loans**
€ Savings deposits	3.4		
Other financial assets	17.9	0.9	**Other financial liabilities**
Non-financial assets	37.7	56.7	**Net worth**
TOTAL	**65.0**	**65.0**	**TOTAL**

Non-financial corporations (NFCs)

(outstanding amounts in EUR tn)

Assets			*Liabilities*
€ Overnight deposits	2.6	4.8	**Bank loans**
€ Savings deposits	0.5		
NB loans + unlisted equity	20.3	22.8	**NB loans + unlisted equity**
Debt securities & listed shares	1.3	9.5	**Debt securities & listed shares**
Other accounts receivable	4.8	4.9	**Other accounts payable**
Net fixed assets	15.5	2.9	**Net worth**
TOTAL	**44.8**	**44.8**	**TOTAL**

Source: ECB (QSA and BSI).
Note: BFIs include insurance corporations, pension funds, non-money market investment funds and other financial intermediaries not classified in the MFI.sector. “PS” stands for private sector.

Acknowledgements
We would like to thank Mitsutoshi Adachi, Ulrich Bindseil Fédéric Holm-Hadulla, Philip Lane, Fabio Panetta, Francesco Pennesi, Andrea Pinna, Anton Van der Kraaij, Isabel Vansteenkiste and Thomas Vlassopoulos for their very helpful comments and suggestions. We would also like to thank Silvia Scopel and Lara-Marie Rausch for excellent research assistance. We are also grateful to participants at seminars organised by the ECB and the Eurosystem and to members of the High-level Task Force on CBDC and the Monetary Policy Committee. The views expressed in this paper are those of the authors and do not necessarily reflect those of the ECB, the Eurosystem, any other institution the authors may be affiliated to, nor those of the people mentioned in these acknowledgements. We are fully responsible for any errors or omissions. Gabriela Silova worked on this paper while employed by the ECB and has in the meantime left the ECB and joined Morgan Stanley. Morgan Stanley disclaimer: "This paper was written in Gabriela Silova's individual capacity and is not related to her role at Morgan Stanley. The analysis, content and conclusions set forth in this paper are those of the authors alone and not of Morgan Stanley or any of its affiliate companies. The authors alone are responsible for the content."

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PDF ISBN 978-92-899-4847-0, ISSN 1725-6534, doi:10.2866/467860, QB-AQ-21-036-EN-N