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Mercati, infrastrutture, sistemi di pagamento

(Markets, Infrastructures, Payment Systems)

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A general framework to assess the smooth implementation of monetary policy: an application to the introduction of the digital euro

by Annalisa De Nicola* and Michelina Lo Russo*

Abstract

This paper proposes a methodological framework for estimating the maximum amount of digital euro (D€) that is consistent with a smooth monetary policy implementation (MPI) in the euro area (EA). To this end, we consider that monetary policy is implemented smoothly following the introduction of the D€ when i) the remaining aggregate liquidity in the EA is sufficient to anchor short-term rates to the deposit facility rate and ii) EA national banking sectors can largely meet D€ demand with excess reserves and additional central bank credit. We estimate that, for a smooth MPI, the maximum amount of D€ should not exceed EUR 1.7 tn under an approach that takes into account the heterogeneity across EA countries and banks and prevents any EA national banking sector from facing a too severe liquidity distress following the introduction of the D€. Our analysis suggests the importance of refinancing operations with a broad collateral framework in the Eurosystem operational framework, due to their key role in allowing the central bank to elastically withstand additional reserve demand stemming from the introduction of the D€.

JEL Classification: E41, E52, E58, G21.

Keywords: central bank digital currency, ECB, Eurosystem, central bank reserves, monetary policy implementation.

Sintesi

Il lavoro propone una metodologia per stimare la quantità massima di euro digitale (D€) che risulti coerente con una ordinata attuazione della politica monetaria nell'area dell'euro (AE). A tal fine, definiamo l'attuazione della politica monetaria come ordinata se dopo l'introduzione del D€: i) la liquidità aggregata rimanente nell'AE è sufficiente per ancorare i tassi a breve termine al tasso sulla *deposit facility* e ii) i settori bancari nazionali dell'AE sono in grado di soddisfare in larga misura la domanda di D€ con l'utilizzo delle riserve in eccesso e un maggiore ricorso al credito di banca centrale. Stimiamo che, per una ordinata attuazione della politica monetaria, la quantità massima di D€ non dovrebbe superare 1.700 miliardi di euro. Tale risultato tiene conto dell'esistente eterogeneità tra i paesi e le banche nell'AE e della necessità di garantire che nessun sistema bancario nazionale si trovi ad affrontare una crisi di liquidità a seguito dell'introduzione del D€. L'analisi suggerisce l'importanza, nell'assetto operativo dell'Eurosistema, di operazioni di rifinanziamento a fronte di una gamma estesa di garanzie, dato il loro ruolo cruciale nel consentire alla banca centrale di assorbire elasticamente il fabbisogno aggiuntivo di riserve derivante dall'introduzione del D€.

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CONTENTS

1. Introduction

This paper proposes a methodological framework for the estimation of the maximum amount of a retail central bank digital currency (CBDC) that is consistent with a smooth implementation of monetary policy and reflects, accordingly, the central bank's response to the resulting liquidity drain.

If a CBDC is issued, end users might substitute banknotes (central bank money) and/or bank deposits (commercial bank money) with the digital currency, with implications on both the banking sector and the central bank's balance sheets (Auer *et al.* 2024; Caccia *et al.* 2024). In the case of a full substitution of banknotes, the CBDC would change the central bank's balance sheet composition on the liability side while leaving unchanged the balance sheet size of both the central bank and commercial banks. In the case of a full substitution of bank deposits, the CBDC might instead lead to a structural shift in banks' funding conditions. Credit institutions would lose a stable and cheap source of funding and might need additional central bank reserves to accommodate the CBDC demand. Brunnermeier and Niepelt (2019) argue that if the central bank has a strong commitment to act as lender of last resort, it can theoretically buffer all the effects of outflows from bank deposits into the CBDC by substituting deposit funding with central bank funding. However, this "neutrality theorem" runs into the physical limit of the amount of liquidity that can be effectively injected by the central bank. This limit relates to the availability of eligible collateral that can be pledged by individual banks to obtain central bank credit or securities that can be purchased by the central bank under a purchase programme. Even if the central bank does not want to fully compensate for the outflows from commercial bank deposits into the CBDC with additional reserves provision, it still needs to ensure that the amount of reserves in the banking sector is consistent with a smooth monetary policy implementation (MPI).

In this paper, we examine the substitution of commercial bank money with the CBDC, while excluding the impact of CBDC issuance on banknote demand. The CBDC we refer to is the so called *digital euro* (D€) explored by the ECB. While the model focuses on the case of a D€, it is sufficiently general to be applicable to other instances where liquidity shocks may impair MPI.

Our methodological framework builds on a definition of "smooth MPI" that accounts for the heterogeneity among euro area (EA) member countries. We acknowledge that EA credit institutions might not be equally equipped to react to the (potential) outflows in retail deposits induced by the D€ issuance as they differ in reserve holdings, funding models and size. For instance, institutions with large funding from retail depositors may suffer more than institutions relying on wholesale funding sources. Furthermore, the extent to which central bank liquidity provision can substitute deposit outflows must be operationally verified both at an aggregate and individual bank level on the basis of available eligible collateral. In our model, we assume that the Eurosystem accommodates banks' demand for reserves after the D€ issuance via credit operations only.

By using bank level data, we first calculate the amount of reserves and additional central bank credit that banks can use to accommodate the D€ demand and then we investigate the impact of the D€ demand on MPI. To this end, we consider that monetary policy is smoothly implemented if i) the remaining EA aggregate liquidity is sufficient to anchor short-term rates in a floor system and ii) each countries' national banking sector is able to accommodate to a large extent the D€ demand with reserves and additional central bank credit.

By running the model based on data as of September 2021,[1] we find that the maximum amount of D€ that does not interfere with a smooth implementation of monetary policy should not exceed EUR 1.7 tn under the proposed approach. This figure is not intended to be used to infer the individual holding limits (i.e. by dividing the aggregate figure by the number of potential D€ holders). Rather, it represents the largest possible amount of D€ in circulation that – based on available reserves and additional central bank credit – would preserve a smooth MPI. The estimated figure should thus be interpreted with caution for two main reasons. First, the framework for the estimation of the maximum amount focuses solely on the implications for MPI and may contribute only from this perspective to the broader assessment on the methodology for the calibration of individual holding limits. This calibration requires a more comprehensive monetary and economic evaluation, including considerations on the potential impact of digital payment solutions on banknote demand, as well as the effects of the D€ on the monetary policy transmission and financial stability. Second, the figure is sensitive to the choice of key parameters, which are designed to illustrate an extreme scenario where, for instance, we assume that banks utilize all their excess liquidity and unencumbered eligible collateral to meet D€ demand.[2]

Our findings bring about a relevant policy implication: taking into account heterogeneity across credit institutions and jurisdictions in the EA is crucial when calibrating the Eurosystem response to a liquidity outflow like the one that would occur if the D€ was issued (Assenmacher and Smets 2024). From an MPI perspective, the most suitable instrument for addressing such heterogeneity are properly designed demand-driven reserve providing operations. Also the 2024

[1] Authors' last available data.
[2] The figure of our extreme scenario is consistent with the preliminary analysis made by the ECB and reported by F. Panetta at the European Parliament in 2022. Accordingly, the D€ in circulation should not exceed EUR 1.5 tn to avoid negative effects for the financial system and monetary policy (Panetta 2022).

review of the Eurosystem operational framework (ECB 2024; Schnabel 2024) confirmed the key role of elastic reserve provision through credit operations with a broad collateral framework.

Related literature. Our contribution to the existing literature is twofold. First, we add to the relatively less explored literature on the implications of CBDC from the point of view of the implementation of the monetary policy. As also shown in Infante *et al.* (2022), most academic literature has focused on the macroeconomic impacts of a CBDC introduction; few studies have examined the interaction between the CBDC and monetary policy implementation. Among these, many papers investigated, from different angles, the mechanics of bank deposit conversion to CBDC on the central bank and the banking sector's balance sheets (Adalid *et al.* 2022, Auer *et al.* 2024, Malloy *et al.* 2022, Caccia *et al.* 2024). Abad *et al.* (2023) further investigated the macroeconomic effects of reserve regime switches associated to increasing levels of CBDC demand. To the best of our knowledge, our paper represents the first attempt to inform the calibration of D€ holding limits based on a possible definition of smooth MPI. Second, we contribute to the strand of literature that proposes quantitative models for the calibration of D€ holding limit. We align with Meller and Soons (2023) in basing our analysis on granular data of individual banks, but we adopt a different perspective. Meller and Soons (2023) simulates how banks' funding structure might respond to different retail deposit outflows based on a constrained optimisation model aimed at maximizing banks' profit. Differently, our approach is rooted in the central bank's perspective and quantifies the maximum amount of D€ that minimizes the risks for a smooth implementation of monetary policy, duly accounting for the heterogeneity across EA countries and banks.

Structure of the paper. Section 2 introduces the conceptual framework. Section 3 describes the underlying data. Section 4 illustrates the model. Section 5 presents the results of the model's application for an illustrative scenario and a sensitivity analysis. Section 6 provides preliminary qualitative considerations on the impact of D€ issuance on the money market. Finally, Section 7 concludes the paper.

2. Conceptual framework

Since its inception, the operational framework of the Eurosystem has been grounded on a broad counterparty framework and a broad collateral framework[3] designed to ensure uniform access to

[3] The counterparty framework establishes criteria that allow a broad range of credit institutions, mainly banks, to participate in Eurosystem monetary policy operations, while safeguarding the Eurosystem from the risk of a counterparty defaulting. Complementing this, the Eurosystem collateral framework regulates the collateralisation of Eurosystem credit operations, providing an additional layer of protection against counterparty default (ECB 2024b).

central bank reserves through open market operations to banks operating in different jurisdictions (Bindseil *et al.* 2017, Cœuré 2016). In the EA bank-based economy, these elements were fundamental for the smooth implementation of monetary policy, while also safeguarding the proper functioning of the money market.

Accordingly, in our methodological framework we introduce three conditions for monetary policy to be smoothly implemented. First, the aggregate amount of reserves should be consistent with the so called Floor Required Excess Liquidity (FREL), that is the minimum amount of liquidity that keeps money market rates anchored to the deposit facility rate[4] under an ample reserve regime (aggregate condition).[5] Second, the provision of central bank reserves should limit the share of banks in liquidity distress in all EA national banking sectors (local condition). Third, money markets distribute reserves throughout the banking system without impairments (market condition). In this paper, we propose a model for the quantitative assessment of the maximum amount of D€ that is consistent with the aggregate and local conditions; as for the consistency of the D€ amount with the market condition, we provide only qualitative considerations.

From a liquidity perspective, the issuance of one unit of D€ has the same implications as the issuance of one additional unit of banknotes, as they are both autonomous factors. Thus, in case the D€ demand replaces banknote demand, no changes are expected in aggregate and individual liquidity conditions. By contrast, if the D€ demand replaces commercial bank money, reserves are drained from the banking sector.[6] Specifically, credit institutions would observe, as a first round effect, a reduction of their deposit base. For the purpose of this work, we define the deposit base as the amount of sight commercial bank deposits held by households and non-financial corporations. The choice of considering commercial banks' euro-denominated sight deposits as the variable at risk in the proposed framework is justified by the need to focus on a form of money that could potentially be converted, any time by end users on demand, for central bank money. Furthermore, sight deposits are in principle used as a means of payment – representing the closest substitute for a D€ designed for this purpose – in contrast to deposits with pre-set maturity, which might be intended as store of value instruments. In a subsequent step, banks have to provide their customers with the requested amount of D€ and –as is the case with banknote demand – this results in a reduction of reserves in circulation. Indeed, to

[4] The deposit facility rate is the rate paid by the Eurosystem to reserves held overnight by banks at the deposit facility. The Governing Council of the ECB decided in March 2024 to continue to steer the monetary policy stance in the vicinity of this rate.
[5] A floor system is an operating framework in which the control of short-term interest rates is ensured by supplying ample reserves and paying interest on those reserves at a policy rate that, in the Eurosystem, is represented by the deposit facility rate. The concept of FREL refers to the optimal level of reserves needed to implement a floor system and for the EA was first introduced by P. Aberg *et al.* (2021); it is typically expressed as a percentage of the banking sector's total assets.
[6] Namely, we assume that one euro of D€ substitutes with one euro of commercial banks sight deposits.

accommodate the D€ demand, banks have to exchange reserves with the central bank. We consider that this might occur through two channels. Firstly, by using their excess liquidity (EL) that is the amount of reserves held in excess of the minimum reserve requirement. Secondly, by using their additional funding capacity (AFC), that is, the amount of additional central bank reserves they can borrow from the central bank, provided that they have eligible unencumbered collateral. We assume that the central bank is willing to satisfy any additional demand for reserves due to the D€ introduction through credit operations, while we exclude the possibility that banks can obtain reserves to react to the D€ via monetary policy asset purchases.[7] If banks accommodate the D€ demand entirely with EL, we would observe a reduction in the size of their balance sheet (by the same amount as the decrease in the deposit base);[8] if banks accommodate the D€ demand with AFC, then a re-composition in banks' liabilities would occur (i.e. the central bank funding increases to compensate for the decrease in the deposit base).[9]

In the end, the use of EL and AFC to accommodate the D€ demand leads to changes in the aggregate and individual liquidity positions, with potential consequences for MPI. Hence we assess what is the maximum amount of D€ that ensures that both the aggregate and local conditions for a smooth MPI are met.[10]

3. The data

This analysis uses bank level information gathered from multiple Eurosystem proprietary databases and related to banks' balance sheets, banks' liquidity position, banks' holdings of eligible unencumbered marketable and non-marketable assets.[11] The sample consists of 1,207 EA credit institutions. The reference date for the input variables is 30 September 2021, except for banks' liquidity position which is expressed as an average value over September 2021.

[7] While we recognize that, at an aggregate level, outright purchases do have a relevant role in keeping the amount of reserves close to the level considered coherent with a floor system and, to a certain extent, may allow to counteract the decline of reserves determined by the issuance of a D€, it cannot be ensured that reserves provided in this way directly and immediately reach the credit institutions most affected by the D€ shock (Schnabel 2024). For this reason, we exclude this possibility from the methodology proposed in this paper.

[8] We assume that banks adapt their balance sheet on the asset side via a reduction in EL; other deleveraging measures are not considered. We also neglect the marginal reduction in the minimum reserve requirements associated with the deposit outflow.

[9] We do not envisage the possibility that banks increase their market funding to react to the deposit base decline. Also, intragroup flows are excluded.

[10] This proposed framework focuses only on the *instant* reactions of the Eurosystem and the banking system to the D€ issuance under an ample reserve environment. Thus, we do not assess the case of a gradual adoption of the D€ and the potential adjustments that banks could put in place in a world with a D€ (e.g. if they adapt their funding model).

[11] The datasets are collected by the ECB and are accessible to the NCBs upon request.

The first dataset consists of the individual bank balance sheet items (IBSI) statistics. In our framework we define the deposit base as the variable at risk, that is the amount of banks' euro-denominated sight deposits held by households and non-financial corporations; the deposit base is equal to EUR 6.4 tn in our sample. We also rely on IBSI statistics to allocate banks into dimensional and funding model clusters. By using a parametric approach, banks are labelled as "large" if their total assets are above EUR 30 bn, "small" if their total assets are below EUR 5 bn and "medium" otherwise. In our sample the majority of banks are small (731, 60% of the sample), followed by medium-sized (346, 29%) and large (130, 11%). By applying a k-means clustering algorithm on a set of four balance sheet variables,[12] we also group banks in three funding model clusters. First, the retail-funded banks are characterised on average by a high reliance (around 70% of their total main liabilities) on deposits from households and non-financial corporations and a low share of wholesale deposits (5%), interbank funding (13%) and debt securities issuance (1%). This is the largest group in our sample (74%), with 895 banks. Second, interbank-funded banks have a higher share of interbank borrowing (66% of total main liabilities) and a lower share of retail and wholesale deposits (9% each) and debt issuance (6%); 127 banks fall within this cluster (11% of the sample). Third, banks with mixed-funding are characterized by a well-diversified funding structure: retail deposits, wholesale deposits, interbank funding and market funding represent around 20% of total main liabilities each. This group includes 185 banks (15% of the sample).[13]

The second dataset consists of banks' liquidity position vis-à-vis the Eurosystem, based on the ECB's Market Operations Database. Total excess liquidity amounts to EUR 3.3 tn in our sample and is heterogeneously distributed across countries. In absolute terms, it is concentrated in the largest EA jurisdictions; in relative terms, i.e. when taking into account the size of the respective banking systems, smaller countries hold a higher share of EL. Banks with a mixed funding structure tend to hold more EL due to the Eurosystem asset purchase programmes, as they often hold the deposits of wholesale clients who are the ultimate sellers of assets. By contrast, interbank and retail funded institutions have negligible shares of wholesale deposits in their liabilities and tend to hold lower shares of EL.

The third dataset relates to banks' holdings of unencumbered eligible marketable assets (UEMA), estimated from the Securities Holdings Statistics Groups (SHS-G) database. For banks reporting in

[12] We use the following balance sheet characteristics as input variables for the statistical clustering: i) the ratio of household and non-financial corporation deposits to total main liabilities; ii) the ratio of total debt securities issued to total main liabilities; iii) the ratio of non-monetary financial institutions deposits to total main liabilities; iv) the ratio of monetary financial institutions deposits to total main liabilities. Balance sheet items not included in the clustering are the amount of deposits with central government, the amount of deposit not denominated in euro and capital and reserves.

[13] The detailed allocation of banks among size groups and funding models is shown in Annex.

the SHS-G, we consider their holdings of securities eligible for monetary policy operations and select those reported either as not encumbered in market transactions or pledged at the Eurosystem. We then compute the collateral value after haircuts of these holdings, by reducing their market value by the valuation haircuts in place at the time of the model estimation, increased by a fixed factor of 20%, to neutralise the effect of the temporary increase in the Eurosystem risk tolerance level related to the pandemic crisis.[14] We also account for additional haircuts in the case of own-used securities. For those banks that do not report in SHS-G,[15] we proxy their UEMA variable by applying the same share over total assets held by their peers. In our sample, we estimate that banks hold an aggregate amount of UEMA equal to EUR 1.1 tn, that would potentially allow them to increase their collateral pools by 55%.

The fourth dataset consists of banks' unencumbered eligible non-marketable assets (UENMA), estimated from the Anacredit database. We consider only credit claims eligible under the ordinary Eurosystem collateral framework and apply conservative average haircuts calculated at the bank/country level where all necessary information about the assets is not available. We net the amount of UENMA by the value of credit claims already pledged at the Eurosystem. The total amount of UENMA for the whole sample is equal to EUR 0.7 tn.

4. The model

Based on the described conceptual framework we build a novel quantitative approach for estimating the maximum amount of D€ that does not impair a smooth MPI.

Let $b \in \mathcal{B}$ be the generic EA bank belonging to our sample. For each $b \in \mathcal{B}$, the D€ introduction determines a percentage reduction x_b of its deposit base Dep_b such that

$$\text{D€} = \sum_{b \in \mathcal{B}} x_b Dep_b. \tag{1}$$

In order to react to the deposit base decline induced by the introduction of the D€, each bank $b \in \mathcal{B}$ may use first a share k of its excess liquidity EL_b (if any), and then (if still needed) a share y of its additional funding capacity AFC_b, i.e. the amount of additional reserves the bank $b \in \mathcal{B}$ can borrow from the central bank based on its eligible unencumbered collateral. If the sum of reserves resulting from these two contributions is not sufficient to accommodate the D€ demand, the bank is in a

[14] See the ECB press releases of 7 April 2020 and 22 April 2020 for the package of collateral easing measures.
[15] They represent 24% of the sample by total assets and 19% by excess liquidity.

situation of liquidity distress. With the aim to identify such banks, for each bank $b \in \mathcal{B}$ and any share x_b of the deposit base, we define the Attention Index $AI_b(x_b)$ as in

(2) $$AI_b(x_b) = \begin{cases} 1, & \text{if } \dfrac{kEL_b + yAFC_b}{x_b Dep_b} < 1. \\ 0, & \text{otherwise} \end{cases}$$

The Attention Index is 1 for banks resulting in liquidity distress after the D€ introduction and it is 0 for all the other cases.

In order to assess the consequences on the MPI of the issuance of the D€, we define the aggregate condition and the local condition.

According to the aggregate condition, whatever the impact of x_b across banks is, the amount of EL, following the liquidity drain, must be equal at least to the FREL, as defined below

(3) $$\sum_{b \in \mathcal{B}} max\{EL_b - x_b Dep_b; 0\} \geq FREL.$$ *aggregate condition*

To account for the local dimension for a smooth MPI, we group EA banks into categories characterized by common features. For instance, the same funding model, size or jurisdiction. Let $\mathcal{C}$ denote the set of all categories and let $C \in \mathcal{C}$ be a particular category; e.g. if banks are grouped on the basis of EA jurisdictions, then $\mathcal{C} = \{AT, BE, CY, \ldots, SI, SK\}$. According to the local condition and for each category $C \in \mathcal{C}$, the sum of total assets of banks in liquidity distress (those with Attention Index equal to 1) should represent no more than a given share z of the total assets of all banks in that category. More in detail

(4) $$\frac{\sum_{b \in C} TA_b \cdot AI_b(x_b)}{\sum_{b \in C} TA_b} \leq z.$$ *local condition for each $C \in \mathcal{C}$*

The choice of z is exogenous and it depends on the extent to which the central bank deems acceptable, from an MPI perspective, that banks belonging to a given category cannot accommodate the D€ demand via EL and AFC. For instance, $z = 7\%$ means that, according to the central bank's assessment, banks representing no more than 7% of total assets in a category (e.g. in a jurisdiction) can fall short of EL and AFC in response to the D€ introduction, without impairing a smooth MPI.[16]

[16] In the reminder of the paper we first present the results of an illustrative scenario for a selected value of z and then we run a sensitivity analysis for different values of z.

To determine the maximum amount of D€, that can be issued by the Eurosystem under both the local and the aggregate conditions, for each category $C \in \mathcal{C}$ and any share z, we define the critical threshold $\bar{x}_C(z)$ as the maximum deposit decline, share x of deposit base, that satisfies the local condition

$$\bar{x}_C(z) = max\left\{x \text{ such that } \frac{\sum_{b\in C} TA_b \cdot AI_b(x)}{\sum_{b\in C} TA_b} \leq z\right\}. \quad (5)$$

Then we compute the minimum threshold among all the categories

$$\hat{x}(z) = min_{C\in\mathcal{C}}\bar{x}_C(z). \quad (6)$$

Calibrating the critical threshold to the minimum value observed across all EA countries (i.e. at the level of the most exposed jurisdiction) is intended to minimize negative implications for a smooth MPI.

Assuming that the deposit base decline affects uniformly all EA banks (and thus all categories), the maximum amount of D€ for each cluster that is consistent with the smooth MPI is

$$MaxD€(z) = \hat{x}(z) \sum_{b\in\mathcal{B}} Dep_b \quad (7)$$

where the choice of z is also constrained by the aggregate condition (3).

The maximum amount of D€ computed with Equation (7) is prudently calibrated based on the category facing the most severe difficulties in addressing the liquidity drain from the D€ introduction.[17] Such an amount reflects the central bank maximum response to the D€ shock in terms of existing reserves and additional reserves provision via credit operations.

5. The results

5.1. The maximum amount of D€ for a smooth MPI: an illustrative scenario

This section presents the results of the model in an illustrative scenario where the key parameters are defined as follows: (a) for the Attention Index, we consider that banks use their EL and AFC up

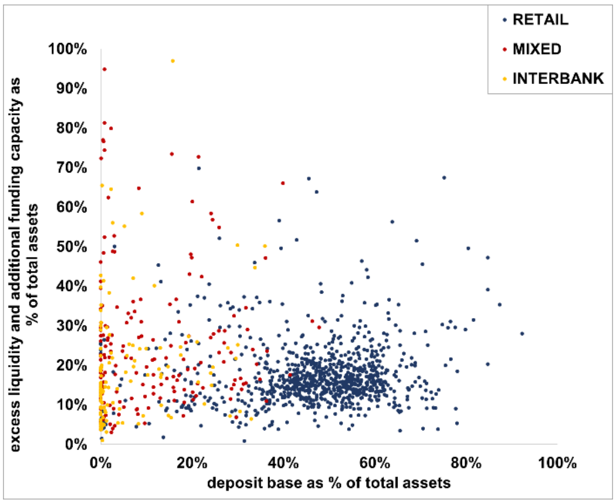
[17] A more realistic case would consider that the D€ shock is distributed proportionally among banks within each category but not across the categories, reflecting differentiated D€ demand across them. When the category under consideration is the jurisdiction, this case aligns with the liquidity management process of national central banks for banknote forecasts (European Parliament, 2017). In such a case, the maximum amount of D€, consistent with the smooth MPI conditions, would be calculated by applying each country's specific critical threshold in Equation (5) to the sight deposit aggregate of the national banking sector and then summing up across all jurisdictions.

to the maximum possible level ($y = 1$, $k = 1$); (b) for the aggregate condition, we assume that the FREL is equal to EUR 1.5 tn, which corresponds to EUR 1.1 tn in our sample; (c) for the local condition, we assume that the set of categories $\mathcal{C}$ is represented by EA jurisdictions and that (d) the share (in terms of total assets) of banks in liquidity distress (i.e. with Attention Index equal to 1) is no more than $z = 7\%$ in the jurisdiction most negatively affected by the D€ introduction. Further insights on the rationale behind the choice of the key parameters are provided in Section 5.2.

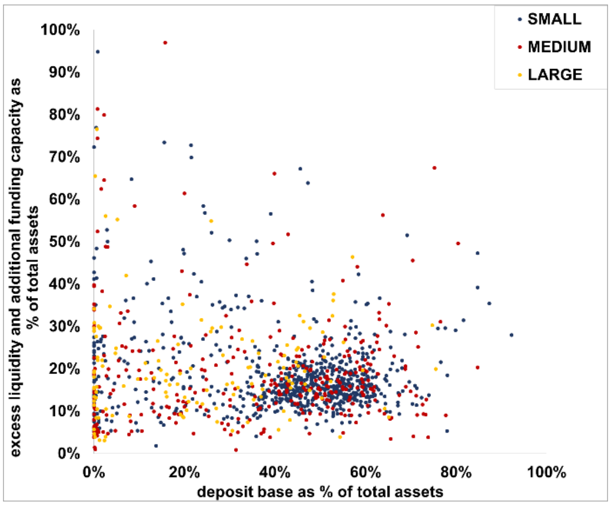
To compute the maximum amount of D€ consistent with a smooth MPI, we estimate the share of deposit base reduction following the issuance of the D€ that is coherent with the aggregate and local conditions.

Figure 1: Relationship between the deposit base, EL and AFC by funding model (a) and size (b)

a)



b)



Sources: Eurosystem databases, own calculations. Data as of September 2021.
Note: The charts show for the sampled banks (points) the amount of EL and AFC over total assets (y-axis) in relation to the amount of deposit base over total assets (x-axis).

Starting with the aggregate condition, we find that for a deposit outflow equal to $x_b = 65\%$ for each bank b in the EA, the EL that remains available to banks in the sample is equal to the FREL (Equation 3), which implies that the central bank should be able to steer short-term rates at the intended policy rate. Nevertheless, if we investigate the individual bank responses, we find that as many as two thirds of banks – 816 over 1,207, representing 30% of the EA total assets – show an Attention Index equal to 1 (Equation 2), i.e. these banks would not be able to accommodate the D€ demand with central bank reserves (EL and AFC). Among them, small retail banks are the majority, given their higher exposure to sight deposits and lower share of EL in their balance sheet (Figure 1). Their limited reliance on wholesale and market funding suggests that small retail banks may not have a wide market access and, thus, could find it difficult to adjust their funding mix via money and/or bond markets. When the share of deposit outflow induced by the D€ introduction is equal to 65%, also several large and medium-sized banks have the Attention Index equal to 1. These larger credit institutions might be better equipped than small banks in adjusting their funding mix towards market funding to replenish their lack of central bank reserves. However, the higher recourse to money markets by larger players could lead to upward pressure on secured and unsecured rates, which might be also exacerbated if a large amount of collateral has already been encumbered with the Eurosystem (in response to the deposit outflows). Overall, even if the aggregate condition is met, the implementation of monetary policy could still be impaired.

This first evidence supports our idea that controlling only for the FREL does not suffice to ensure a smooth MPI in the EA.

Figure 2: Share of deposit base decline – critical thresholds $\bar{x}_C(z)$ – for which no more than $z = 7\%$ (by total assets) of banks in each selected EA country (Ctry) fall short of available resources

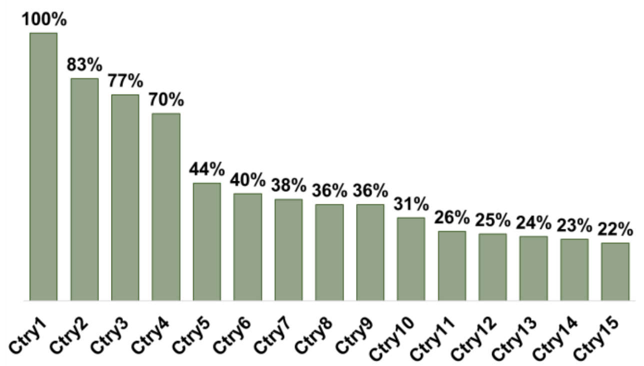
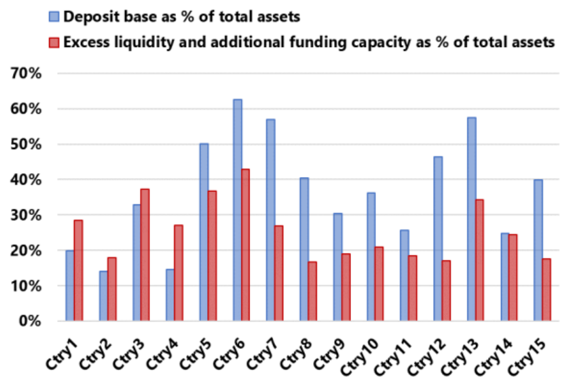


Figure 3: Deposit base and available resources over total assets, for selected EA countries



Sources: Eurosystem databases, own calculations. Data as of September 2021.
Note: Figures exclude data for 4 EA jurisdictions due to the limited representativeness of these countries' banking sectors (total assets in the sample are below 70%), that would have led to biased critical thresholds.

Hence we control also for the local condition at country level and we compute the share of deposit base decline – i.e. the critical thresholds $\bar{x}_C(z)$ as per Equation (5) – following the D€ introduction for which no more than 7% of banks' total assets in each jurisdiction fall short of EL and AFC. The results are shown in Figure 2: we find high dispersion across countries' critical thresholds, which span from 100% to 22%. Specifically, in few countries where the size of the deposit base is lower compared to the sum of EL and AFC, the critical threshold reaches high values (Ctry1 100%, Ctry2 83%, Ctry3 77%, Ctry4 70%). Ctry1 represents the extreme case in this regard: a critical threshold equal to 100% indicates that even if 100% of sight deposits were drained following the D€ shock, less than 7% of this country's banks (by total assets) would be in liquidity distress; this is because nearly 80% of these banks hold an amount of available resources higher than their deposits base. For the rest of the countries, instead, the opposite is true and the level of the critical threshold depends on how the difference between the available resources and amount of sight deposits is distributed among banks (Figure 3). In those countries where this difference is relatively larger for medium-sized banks, the critical thresholds stand at lower values.

Following Equation (6), we identify the minimum critical threshold among all countries, that in our illustrative scenario corresponds with $\hat{x}(z) = 22\%$ of Ctry15. When this level of D€ shock is applied, almost only banks with a retail funding model experience a shortage of resources to counteract the decline in sight deposits. They are characterized by a lower amount of EL and AFC (9% over total assets) compared to their peers (18% on average for the whole group) and by a higher reliance on sight deposit funding (56% versus 47%). On aggregate, banks in liquidity distress account for 2.3% of EA total assets. According to the proposed approach outlined in Equation (7), we apply the identified minimum critical threshold to the deposit base of each bank in our sample and we ultimately estimate that for the whole EA a maximum amount of D€ equal to EUR 1.7 tn would be consistent with a smooth MPI. Of this amount, 82% would be financed with EL, 16% with AFC; the remaining 2% represents the share of D€ that banks with AI=1 are unable to offer with available resources.[18]

5.2. Sensitivity analysis of the local condition z

The results of the illustrative scenario are sensitive to the selection of the key parameters for the Attention Index (k and y), the aggregate condition (the level of FREL) and the local condition (the category and the level of z). The decision to fully use EL ($k = 1$) and AFC ($y = 1$) to calculate the Attention Index aims at presenting a scenario with the largest possible central bank accommodation of the deposit base decline following the D€ introduction through existing and additional reserves provision via credit operations.[19] For the aggregate condition, several estimates exist in the literature; we aligned with Altavilla *et al.* 2023, computing the FREL as 4% of the EA banking sector total assets. The choice of the category and level of z depends on what the Eurosystem considers coherent

[18]The results of our illustrative scenario are sensitive to the level of available resources and sight deposits at September 2021. Nevertheless, it is likely that the model would gain similar results in a more recent data point, for the following reasons: (i) even if reserves are less abundant, the aggregate condition is unlikely to become binding compared to the local condition, as it is still met for a share of deposit base decline far higher than the one chosen when accounting for the local condition (65% vs 22%); (ii) past experience in the EA shows that reserves injected through asset purchases accumulated in few banks and jurisdictions, resulting the richest of EL: the gradual quantitative tightening has not changed this picture substantially; (iii) the runoff of TLTROs has a nearly neutral net effect on the total amount of available resources, as most repayments were made with EL while determining a parallel increase in AFC; (iv) sight deposits held by households and non-financial corporations slightly declined since September 2021, implying a reduction in the variable at risk.

[19] While the assumption that the individual banks would use all EL to respond to D€ demand may still reflect a physiological situation, the assumption that a bank uses its entire AFC to request additional reserves represents an extreme scenario as, under ordinary conditions, it is unlikely that a bank operates without any available collateral, other than the assets encumbered at the central bank.

with a smooth MPI and an orderly monetary policy transmission. For the category, we selected the EA jurisdictions to take into account that a smooth MPI requires that banks operating in different jurisdictions should uniformly access central bank reserves when needed (Cœuré 2016). For the level of z, instead, no specific stream of research provides guidance for its calibration. Thus we run a sensitivity analysis to verify which level of z could align with a smooth MPI.

In our framework, increasing values of z imply that the Eurosystem deems acceptable, from an MPI perspective, that a greater share of EA banks can fall short of EL and AFC in response to the D€ shock without impairments for a smooth MPI.

As illustrated by Auer *et al.* (2024) in their literature review, most of existing quantitative exercises on the impact of CBDC on banks' balance sheets reflects CBDC take-up scenarios for values lower than 32% of aggregate banks' sight deposits. In our model, this share is represented by the critical threshold $\bar{x}_C(z)$ (Equation 6) and corresponds to $z = 26\%$. Thus, we run the sensitivity analysis for values of $z \leq 26\%$ (Table 1).

Table 1: Sensitivity analysis of the local condition z: associated critical thresholds, banks in liquidity distress and maximum amount of D€

Local condition *share of banks in liquidity distress (by total assets) in the most affected jurisdiction*	z	%	1%	3%	5%	7%	10%	26%
Critical Threshold	$\bar{x}_C(z)$	%	9%	13%	19%	22%	24%	30%
Banks in liquidity distress	$AI_b(x_b) = 1$	*number*	6	19	65	100	162	349
		share of EA total assets (%)	0.2%	0.6%	1.7%	2.3%	3.1%	6.0%
Amount of D€	$MaxD€(z)$	*EUR tn*	0.7	1.0	1.5	1.7	1.9	2.3

Sources: Eurosystem databases, own calculations. Data as of September 2021.
Note: The table shows for each level of z (representing the maximum share of banks in liquidity distress, by total assets, in each EA jurisdiction): i) the critical threshold $\bar{x}_C(z)$ representing the share of deposit base decline that applies to each EA bank; ii) the number of banks with AI=1 and their weight in terms of total assets over the whole EA banking sector; iii) the amount of D€ that derives from the application of the critical threshold to the deposit base of each EA bank.

For $z = 26\%$ nearly one third of banks (349 with Attention Index =1), representing 6.0% of EA total assets, would lack sufficient resources to absorb the D€-induced deposit outflow. Banks in liquidity distress belong to all three dimensional groups and are mainly retail-funded banks. With declining values of z, the number of banks that are not able to fully absorb the deposit outflow with available resources declines substantially: for $z = 10\%$ it halves to 162 and for $z = 5\%$ it further reduces to 65. Overall, the sensitivity analysis confirms that, independently from the z, retail banks are always the most exposed to the risks stemming from the D€ introduction while, for the other funding models, only banks that exhibit a lower share of available resources and higher share of sight deposits compared to their peers are hit. Moreover, when the D€ issuance leads to a sizable reduction in the deposit base (i.e. more than 13%, corresponding to $z = 3\%$), retail institutions of larger size start being under liquidity distress (Table 2).

Table 2: Sensitivity analysis of the local condition z: banks with Attention Index = 1 by funding model (a) and size (b)

a)

Banks with Attention Index = 1	Local condition (z)	1%	3%	5%	7%	10%	26%	All banks
Mixed	Number	-	-	-	-	1	2	185
	Available resources over total assets	-	-	-	-	7%	9%	27%
	Sight deposits over total assets	-	-	-	-	30%	33%	11%
Interbank	Number	-	-	-	1	1	3	127
	Available resources over total assets	-	-	-	6%	6%	7%	19%
	Sight deposits over total assets	-	-	-	33%	33%	31%	6%
Retail	Number	6	19	65	99	160	344	895
	Available resources over total assets	4%	6%	8%	9%	10%	13%	18%
	Sight deposits over total assets	62%	59%	57%	56%	55%	54%	47%

b)

Banks with Attention Index = 1	Local condition (z)	1%	3%	5%	7%	10%	26%	All banks
Large	Number	-	-	5	5	8	11	130
	Available resources over total assets	-	-	8%	8%	7%	9%	21%
	Sight deposits over total assets	-	-	49%	49%	47%	48%	24%
Medium	Number	5	15	31	42	52	96	346
	Available resources over total assets	3%	6%	7%	8%	9%	11%	19%
	Sight deposits over total assets	59%	60%	57%	56%	54%	54%	35%
Small	Number	1	4	29	53	102	242	731
	Available resources over total assets	5%	5%	9%	10%	11%	13%	19%
	Sight deposits over total assets	78%	53%	58%	57%	56%	54%	41%

Sources: Eurosystem databases, own calculations. Data as of September 2021.
Note: The tables show for each level of z the number of banks with Attention Index = 1 and their average share of available resources (EL and AFC) and sight deposits over total assets, for (a) funding model and (b) size groups. On the right side of the tables, the statistics of the three funding models and dimensional groups are reported for comparison.

To determine a non-arbitrary value of z for our illustrative scenario (Section 5.1), we referenced the March 2023 crisis of US regional banks. Despite this crisis was not caused by a structural change akin the potential issuance of a D€, it exemplifies a situation in which a shock on banks' sight deposits triggered the central bank intervention with additional reserves provision. Specifically, in that crisis, a massive and fast deposit outflow originated at Silicon Valley Bank (SVB) and, in the subsequent days, it spread to Signature Bank and First Republic Bank. These three banks represented the 2.3% of US banking sector's total assets and their liquidity distress caused the Fed decision to launch the Bank Term Funding Program (BTFP) "*to make available additional funding to eligible depository* *institutions in order to help assure banks have the ability to meet the needs of all their depositors*" (Fed, 2023).[20]

In this regard, we refer to the 2.3% share of the three US banks' total assets in liquidity distress over US banking sector's total assets as a possible "aggregate" trigger point that could impair a smooth MPI. To apply it to the EA context, we need to account for the EA multi-country nature and, accordingly, identify the "country" trigger point – represented by the z parameter in our framework – that aligns with the chosen "aggregate" level. As shown in Table 1, the 2.3% "aggregate" trigger point corresponds to a "country" trigger point z equal to 7%. This means that banks in liquidity distress across the *entire* EA represent 2.3% of total EA banking sector assets when, *in each EA country*, banks in liquidity distress do not exceed 7% of the respective national banking sector's total assets.[21] Based on this value of the z parameter, the maximum amount of D€ consistent with a smooth MPI should not be higher than EUR 1.7 tn, as shown in our illustrative scenario (Table 1).

6. Preliminary considerations on the EA money market and the Eurosystem footprint

In principle, individual banks could respond to the substitution of sight retail deposits with the D€ in different ways, namely through i) the recourse to Eurosystem funding, ii) the recourse to market funding, iii) the deleveraging of their balance sheet. Actions (i) and (ii) might have direct and indirect effects on money markets, whose magnitude depends – among other things – on the substitution rate between sight retail deposits and the D€, the cluster (in terms of size and funding model) of the affected credit institutions and the monetary policy operational environment (aggregate liquidity conditions, collateral and counterparty framework).

In this paper, we illustrate the case of higher recourse to central bank funding to assess the impact on a smooth MPI. When this happens, the central bank balance sheet size increases and so does the Eurosystem footprint in financial markets, with potential implications on market functioning. First, repo markets are expected to be largely affected via two channels (BIS 2015): (i) the scarcity channel, as a large amount of assets would be encumbered in credit operations; (ii) the structural channel, that reflects the central bank decisions on which assets are accepted in its operations. The magnitude of such effects on EA collateral markets depends on the size of Eurosystem operations and on the level of scarcity of high quality and liquid assets. Second, the high engagement of the Eurosystem that

[20] On March 9 2023, SVB recorded deposits withdrawals equal to 40% of its total assets; on March 10, deposit outflows reached 20% and 17% of their total assets, respectively, for Signature Bank and First Republic Bank (NY State Department of Financial Services 2023; OIG 2023); on March 12, the Federal Reserve announced the launch of the Bank Term Funding programme (Fed 2023).

[21] Moreover, the Advisor Scientific Committees report (ESRB 2024) shows that a large part of the EU banking system would not be able to cope with runs like those at Silicon Valley Bank or First Republic with available liquidity (a share of 10% of banks in terms of total assets in the EU banking system would have been in liquidity distress).

stems from the introduction of a D€ automatically reduces leeway for MPI in upcoming shocks or crises (in the extreme case where D€ only replaces deposits). It is key to have both in mind when investigating the impacts of the D€ introduction and calibrating its amount in circulation as well as the expected benefits and costs of an increased financial market footprint.

Individual banks might alternatively, or in addition, decide to increase their market funding via secured or unsecured money markets. In such a case, the impact of introducing the D€ on the EA money market – in terms of volumes and prices – would be highly uncertain and depend on multiple factors. Among the most relevant ones, the amount of excess reserves in the system, the willingness of banks to redistribute reserves in the market also considering the regulatory constraints, the role of non-bank financial institutions as liquidity providers for the banking sector. If the ECB decides to issue a D€, these aspects deserve to be assessed through an in-depth analysis.

7. Conclusions

We propose a methodological framework for the estimation of the maximum amount of D€ that is consistent with a smooth MPI in the EA. We focus on the substitution of sight retail deposits with the D€ and estimate the leeway that EA banks have on their balance sheets to finance the D€, via a reduction of their EL and/or via a larger recourse to central bank funding. We consider that monetary policy is implemented smoothly if two conditions are verified: i) the EA aggregate liquidity is at least equal to the FREL and ii) a non-negligible share of banks in each country has enough reserves to accommodate the D€ demand. We find that accounting for this second condition is particularly binding in the EA banking sector, where heterogeneity is a relevant fact and liquidity is unevenly distributed across banks and countries. Indeed, if the maximum amount of D€ is calibrated based solely on the FREL, a large number of banks would lack the resources to finance the demand of D€ with EL and additional Eurosystem credit. By accounting for the cross-country dimension, we estimate that the maximum amount of D€ should not exceed EUR 1.7 tn to prevent any EA national banking sector from facing a too severe distress following the D€ introduction. This amount represents the largest possible amount of D€ in circulation beyond which a smooth MPI might be challenged and it is not intended to be used to infer the individual holding limits. Instead, our methodological framework aims to contribute to the broader assessment on the methodology for the calibration of individual holding limits, from the MPI perspective.

Our findings have one main policy implication. The heterogeneity across credit institutions and, consequently, across countries is crucial to properly assess the Eurosystem response to a liquidity drain like the one occurring if the D€ is issued and substitutes with banks' sight deposits. In this regard, the importance of refinancing operations with a broad collateral framework emerges, due to their key role in allowing the Eurosystem to elastically withstand additional reserve demand stemming from the introduction of the D€. These operational framework design features are preconditions aimed at ensuring that no categories of banks or jurisdictions are left behind. Their role in preserving adequate access to central bank reserves for all banks across the EA was confirmed by the 2024 review of the Eurosystem's operational framework (ECB 2024; Schnabel 2024).

An interesting avenue for future research would be to account for bank characteristics when studying the implications of the D€ introduction. The assumption of the uniform distribution of the D€-induced deposit outflow among banks could be relaxed and other inputs might be included in the methodological framework (e.g. users' payments attitudes, users' age). Furthermore, the role of interbank and intra-group liquidity and funding flows might also be included in the assessment of banks' leeway.

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