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Evaluation of sight deposits and central bank digital currency

Michele Azzone[1,2], Emilio Barucci[*,2]

Department of Mathematics, Politecnico di Milano, Italy

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ABSTRACT

We provide a market-based evaluation of sight deposits of banks when Central Bank Digital Currency (CBDC) is issued. We investigate the effects of different adoption rates (moderate, large or capped adoption), of different remuneration schemes and of the possibility of a bank-run. We perform the analysis at the aggregate level for the Euro area and the United States. We show that the effect of CBDC on deposit market value is small unless a large adoption rate is considered. The remuneration scheme plays a significant role only in the moderate/capped adoption scenario in relative terms and in a high interest rate environment. Instead, the possibility of a bank-run calibrated on the experience of the Euro area and of Greece during the debt crisis has little effect on the value of deposits even if a CBDC is introduced.

1. Introduction

The debate on the design of the Central Bank Digital Currency (CBDC) is flourishing because several welfare, technological, and financial intermediation issues are on the table. A careful examination of its design is requested before proceeding with its issuance. In this paper, we deepen the implications for financial intermediation and stability investigating how the introduction of retail CBDC would affect the banks' balance sheets at the aggregate level in the Euro area and in the United States.[3]

Differently from other papers addressing the topic through structural models or making some high-level assumptions on the adoption of CBDC (Bank of International Settlements, 2021; Garcia et al., 2020, see e.g.,), we provide a market-based evaluation of sight deposits of banks assuming that the CBDC is introduced in different scenarios: pure transactional adoption, remuneration of CBDC, and possibility of a bank-run. The effect on the balance sheet of banks is calibrated from market data building on the approach provided by Jarrow and Van Deventer (1998).

CBDC is a digital form of central bank's fiat currency other than cash and bank reserves. Depending on its features, CBDC provides both a store of value and a payment method that competes with cash and deposits. There is a large literature on welfare, banking intermediation, and financial stability effects associated with its introduction. The main trade-off being represented by the welfare improvement for citizens (CBDC entails no risk and allows to address payment frictions) and bank disintermediation which is associated to an increase of funding costs, lower credit to the economy and amplified bank-runs in turbulent periods, see Agur et al. (2022), Allen et al. (2022), Andolfatto (2020), Brunnermeier and Niepelt (2019), Burlon et al. (2022), Chiu et al. (2019), Jabbar et al. (2023), Keister and Sanches (2022) and Williamson (2021, 2022).

According to Jarrow and Van Deventer (1998), the value of sight deposits is given by the expected value under the risk-neutral probability measure of the gain that the bank obtains by investing deposits in the money market. We develop our analysis calibrating

* Corresponding author.
E-mail address: emilio.barucci@polimi.it (E. Barucci).

[1] The paper was written when the first author was working at the European Central Bank. The opinions presented in the paper belong to the authors.

[2] Both authors contributed equally to all parts of the submitted manuscript.

[3] Retail CBDC should be used by citizens, while wholesale CBDC should be used by banks to settle reserve transactions among them.

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money interest rate, official rate and deposit volume from market data and then we investigate the effect on the value of deposits associated with the introduction of CBDC under different scenarios. We investigate the topic in three steps. First of all, we consider three scenarios where the CBDC is adopted as a payment instrument based on Adalid et al. (2022), then we add remuneration considering different types of schemes and finally we consider the possibility of a bank-run in the Euro area with a magnitude similar to the one that occurred during the sovereign debt crisis.

We show that the effect of CBDC on banks' balance sheets in the Euro area and in the US is limited, unless the extreme scenario of a large adoption rate is considered. In case of a massive adoption of CBDC, the reduction of the value of deposits would be between 30 and 50%, otherwise the loss for the banking system would be smaller than 10%. The remuneration scheme plays a significant role only in the moderate/capped adoption scenario in relative terms. The analysis provides a clear ranking among the remuneration schemes under discussion: the lowest loss in the deposit market value is obtained in case of no remuneration (CBDC like cash), the highest loss is obtained in case of CBDC remunerated as bank reserves, the option based remuneration scheme proposed in Bindseil (2020) and Bindseil and Panetta (2020) lies in the middle allowing banks to limit the effects of disintermediation. Remuneration of CBDC leads to a higher reduction of deposit value, the effect increases with policy rates, hence it is limited in a low interest rate environment. The possibility of a systemic bank-run calibrated on the experience of the Euro area and of Greece during the debt crisis has little effect on the market value of deposits. We can conclude that the CBDC should not be perceived as a real threat for financial stability and global financial stress (see also, Stolbov et al., 2022, tab.7).

The paper is organized as follows. In Section 2, we provide a review of the literature. In Section 3, we introduce the model and discuss its main properties. In Section 4, we obtain the formula for pricing of deposits. In Section 5, we describe the dataset and the parameters' estimation. In Section 6, we present the main results on the effects of CBDC on sight deposit evaluation. Finally, Section 7 concludes.

2. Review of the literature

The literature provides some attempts to estimate the adoption of CBDC through structural economic models. In a dynamic stochastic general equilibrium setting, Burlon et al. (2022) argues that the welfare-maximizing amount of CBDC in the Euro area lies between 15 and 45% of quarterly GDP. Up to now, as there is no experience with the issuance of CBDC, especially in advanced economies, there is no empirical information on the actual CBDC demand (see Adalid et al., 2022). Some papers assess the adoption rate through surveys on customers' attitudes. Huynh et al. (2020) estimate the adoption of CBDC as a payment method considering the Bank of Canada's Methods of Payment Survey. Comparing CBDC to cash, credit, and debit card, they estimate a probability of adoption between 0.19 and 0.25, but effective usage probability is not high, lowering transaction costs could significantly improve the adoption probability. Investigating the same survey, Li (2021) estimates the adoption of CBDC concentrating on its role as store of value. He shows that households would hold around 4 and 55% of their liquid assets in CBDC depending on whether it is more cash-like or deposit-like. Adoption is linked to several features of CBDC; varying its remuneration (from 0 to 0.1%), demand would go up by around 8%–18%. The relevance of remuneration of CBDC in determining its adoption is confirmed by a survey on the Dutch market presented in Bijlsma et al. (2021) showing that if the remuneration rate is equal to that of the saving account then the fraction of people adopting the CBDC would be 54%, in the case of a 0.25% lower rate the adoption rate would result in 31%. The experiment performed in Borgonovo et al. (2022) confirms the relevance of remuneration (coupled with anonymity) as a driving force of the adoption rate of a new form of money.

A less structured approach is proposed in several policy papers. Adalid et al. (2022) consider three scenarios: moderate adoption (for retail payments only), large adoption (for retail payments and storage of value), capped adoption (CBDC holding capped at 3.000 euro) splitting the demand for CBDC between deposits and banknotes. We point out that the choice of these scenarios is not linked to their likelihood but only aims at illustrating three different levels of demand for CBDC. An exercise replicating the analysis of Bindseil (2020) for G20 economies assuming that the adoption of CBDC is driven by incomes of people suggests that the domestic demand for CBDC could range between 4 and 12% of bank funding, see Bank of International Settlements (2021). Bank of England (2021) considers a scenario with the conversion of 20% of household and non-financial deposits in CBDC.

Several papers point out the relevance of remuneration of CBDC to tune the adoption rate. A low remuneration would dampen the adoption of CBDC. In case banks have a monopolist power, issuing CBDC would lead to an increase of lending provided that its remuneration rate is lower than that of reserves, see Andolfatto (2020) and Chiu et al. (2019). Agur et al. (2022) show that when there are network effects, there exists an equilibrium with non vanishing cash allowing for a negative remuneration. In a perfectly competitive environment, Keister and Sanches (2022) show that the deposit outflow is a significant phenomenon but the remuneration of CBDC mitigates it, in particular, the interest rate should be high if investment frictions are small and low (or even negative) if frictions are high. Burlon et al. (2022) show that the amount of CBDC in circulation could be controlled by setting a negative interest rate.

A side effect of CBDC is that it may exacerbate bank-runs in particular if it is remunerated, see Williamson (2021). To limit the outflow in a crisis event, central banks are considering the possibility of introducing a cap on holdings of CBDC, see Kumhof and Noone (2021), or a two-tier remuneration mechanism penalizing large amounts of CBDC, see Bindseil (2020) and Bindseil and Panetta (2020).

Although the above cited papers provide some insights on the welfare consequences associated with the adoption of CBDC, little is known about its effects on the balance sheet of banks. Burlon et al. (2022) show that bank evaluation and lending would be negatively impacted in a limited measure. Adalid et al. (2022), analyzing the three scenarios presented above, show that the first and the third scenario can be addressed by banks autonomously, while the second one would require an increase of funding from the

European Central Bank (ECB). Garcia et al. (2020) consider three scenarios for the Canadian banking system with a conversion of 5%–10% of bank assets (5%–33% of deposits), even in the case of a large adoption the return on equity of banks would decrease by less than 100 basis points. Bank of International Settlements (2021) consider banks in advanced countries and estimate that with an outflow of deposits due to the adoption of CBDC up to 25% of total assets of banks, their return on equity would go down up to 90 basis points and, keeping constant banks' profitability and liquidity, the lending rate would go up to 70 basis points. This evidence is reassuring about the fact that CBDC would not significantly harm banks' balance sheets. However, it may hurt vulnerable banks and funding shortages may propagate to other sectors triggering large moves in security prices, see Castrén et al. (2022), inflation effects should be limited but financial stability may be at risk, see Chen and Siklos (2020).

3. The model

The model builds on the one proposed by Jarrow and Van Deventer (1998) for the evaluation of sight deposits, see also Kalkbrener and Willing (2004) and Nyström (2008).

We denote by:

- $r(t)$ the market interest rate
- $i(t)$ the deposit interest rate
- $r^{DF}(t)$ the deposit facility interest rate set by the central bank
- $r^{C}(t)$: the interest rate of the CBDC.

We assume that the market interest rate evolves according to a Vasicek model with stochastic long-term value, see Vasicek (1977):

$$dr(t) = a(h + r^{DF}(t) - r(t))dt + \sigma dW(t) \tag{1}$$

$r(t)$ fluctuates around the stochastic deposit facility rate augmented by a constant h. If $r(t)$ is lower (higher) than $r^{DF}(t) + h$, then it tends to increase (to decrease). The model is the one considered in Jarrow and Van Deventer (1998) with a stochastic long-term level that depends on the policy rate. Following Antonelli et al. (2013), we define the market interest rate directly under the martingale Q measure (risk neutral martingale measure).

By no-arbitrage arguments, we should impose $r(t) \geq r^{DF}(t)$: the market interest rate is higher than the rate at which the central bank remunerates reserves otherwise a free lunch would be at the disposal of the bank. Actually, as shown in Arrata et al. (2020), this is what happened in the Euro area for secured debt since 2015, when the Asset Purchase Program by the ECB caused a scarcity of collateral which impeded banks to exploit arbitrage opportunities. As a consequence, a negative spread between the repo rate and the deposit facility rate originated in Germany and France. Excluding these exceptional times for secured debt, the market interest rate for unsecured debt is usually above the deposit facility rate. The model in (1) does not preclude the possibility of the market interest rate going below the deposit facility rate, however, a positive h (to be estimated from market data) renders unlikely that event, moreover mean reversion (positive a) implies a low persistence of the market interest rate below the deposit facility rate.

As far as the deposit facility rate is concerned, we assume that $r^{DF}(t) \in M_1([0,T])$, i.e., it belongs to the class of real valued, progressively measurable processes $X(t)$ such that $\int_0^T X(t)dt < \infty$ a.s. Denote $\mathcal{G}_t$ the filtration generated by $r^{DF}(t)$. In what follows, we derive the joint probability distribution of $r(t)$ and $\int_0^t r(s)ds$ conditioned to $\mathcal{G}_t$, i.e., the probability distribution of the market interest rate and of its integral, conditional on the deposit facility rate.

Proposition 1. *Conditioned to* $\mathcal{G}_t$

$$\begin{pmatrix} r(t) \\ \int_0^t r(s)ds \end{pmatrix} \stackrel{d}{=} N\left(\begin{pmatrix} \mu_1(t) \\ \mu_2(t) \end{pmatrix}, \begin{pmatrix} S_{1,1}(t) & S_{1,2}(t) \\ S_{2,1}(t) & S_{2,2}(t) \end{pmatrix} \right) \quad , \tag{2}$$

where

$$\mu_1(t) = e^{-at}r(0) + a\int_0^t e^{a(s-t)}(r^{DF}(s))ds$$

$$\mu_2(t) = r(0)\int_0^t e^{-as}ds + a\int_0^t \int_0^s e^{a(u-s)}(r^{DF}(u))du\,ds$$

$$S_{1,1}(t) = \frac{\sigma^2}{2a}\left(1 - e^{-2at}\right)$$

$$S_{2,2}(t) = \frac{\sigma^2}{a^2}\left(t - \frac{3}{2a} + \frac{2}{a}e^{-at} - \frac{e^{-2at}}{2a}\right)$$

$$S_{2,1}(t) = S_{2,1}(t) = \frac{\sigma^2}{a^2}\left(1 - e^{-at} + a\,e^{-2at}t\right) \quad ,$$

a, σ, h are the Vasicek parameters in Eq. (1) and r^{DF} is the central bank deposit facility rate.

Proof. The interest rate $r(t)$ is a process of Hull and White (2001) type. We can solve the stochastic differential equation conditioning to $\mathcal{G}_t$

$$r(t) = e^{-at}r(0) + a\int_0^t e^{a(s-t)}(h + r^{DF}(s))ds + \sigma e^{-at}\int_0^t e^{as}dW(s) \quad .$$

Thus, $r(t)$ is a Gaussian random variable with mean

$$\mu_1(t) := e^{-at}r(0) + a\int_0^t e^{a(s-t)}(h + r^{DF}(s))ds$$

and variance $S_{1,1}(t) = \frac{\sigma^2}{2\alpha}\left(1 - e^{-2\alpha t}\right)$.

We can also compute $\int_0^t r(s)ds$ as follows:

$$\begin{aligned}\int_0^t r(s)ds &= r(0)\int_0^t e^{-as}ds + a\int_0^t\int_0^s e^{a(u-s)}(h + r^{DF}(u))du\,ds + \sigma\int_0^t e^{-as}\int_0^s e^{au}dW(u)ds \\ &:= \mu_2(t) + \sigma\int_0^t e^{-as}\int_0^s e^{au}dW(u)ds \\ &= \mu_2(t) + \sigma\int_0^t e^{au}dW(u)\int_u^t e^{-as}ds \\ &= \mu_2(t) + \frac{\sigma}{a}\int_0^t \left(1 - e^{-a(t-u)}\right)dW(u) \ .\end{aligned}$$

Thus, $\int_0^t r(s)ds$ is a Gaussian random variable with mean $\mu_2(t)$ and variance

$$S_{2,2}(t) := \frac{\sigma^2}{a^2}\int_0^t \left(1 - e^{-a(t-u)}\right)^2 du = \frac{\sigma^2}{a^2}\left(t - \frac{3}{2a} + \frac{2}{a}e^{-at} - \frac{e^{-2\alpha t}}{2a}\right) \ .$$

Moreover, the covariance between $r(t)$ and $\int_0^t r(s)ds$ is

$$S_{1,2}(t) := S_{2,1}(t) = \frac{\sigma^2}{a}e^{-at}\int_0^t \left(1 - e^{-a(t-u)}\right)e^{au}du = \frac{\sigma^2}{2a^2}\left(1 - 2e^{-at} + e^{-2at}\right) \ .$$

This proves the result. □

We follow Jarrow and Van Deventer (1998) modeling the interest rate of sight deposits as

$$i(t) = i(0) + \beta_0 t + \beta_1\int_0^t r(s)ds + \beta_2(r(t) - r(0)) \tag{3}$$

and deposit volume as

$$D(t) = D(0)e^{\alpha_0 t + \alpha_1\int_0^t r(s)ds + \alpha_2(r(t)-r(0)) - \alpha_3\int_0^t r^C(s)ds - \psi^c(t)}. \tag{4}$$

By conditioning with respect to $\mathcal{G}_t$, the amount of deposit $D(t)$ at time t is lognormal, where its exponent has mean $\alpha_0 t + \alpha_1\mu_2(t) + \alpha_2(\mu_1(t) - r(0)) - \alpha_3\int_0^t r^C(s)ds - \psi^c(t)$ and variance $\alpha_1^2 S_{2,2}(t) + \alpha_2^2 S1,1(t) + 2\alpha_1\alpha_2 S1,2(t)$.

The deposit volume equation includes the term $\alpha_3\int_0^t r^C(s)ds$ that models the elasticity of deposit outflow to the remuneration of CBDC and a deterministic time-dependent term $\psi^c(t)$ which is linked to the CBDC adoption for payment/transactional considerations (independently of its remuneration). We choose to model the relationship between deposit volume and CBDC remuneration in this way so that the derivative of $\log(D(t))$ with respect to time t linearly depends on $r^C(s)$. We point out that α_3 and $\psi^c(t)$ are not calibrated from market data, they are chosen according to a scenario analysis taking the models on interest rate of sight deposits and on deposit volume as given, see Section 6. As a matter of fact, a full calibration of the model from market data would not be possible. Note that remuneration of CBDC with a positive α_3 leads to a reduction of deposit volume.

4. Pricing sight deposits

As in Jarrow and Van Deventer (1998), the value of deposits is given as the expected value under the risk-neutral market probability measure of the gain that the bank obtains by investing deposits in the money market:

$$V_D(0) = \mathbb{E}^Q\left(\int_0^\tau \frac{D(t)(r(t) - i(t))}{B(t)}dt\right) \ , \tag{5}$$

where

$$B(t) = e^{-\int_0^t r(s)ds}$$

is the stochastic discount factor. In what follows, we consider a five year horizon ($\tau = 5$). This approach to evaluate sight deposits assumes that the bank can invest instantaneously (e.g. overnight) deposits in the money market.

By conditioning with respect to $\mathcal{G}_\tau$ the value of deposits $V_D(0)$ can be rewritten as:

$$\begin{aligned}V_D(0) &= \mathbb{E}^Q\left(\int_0^\tau \frac{D(t)(r(t) - i(t))}{B(t)}dt\right) \\ &= \mathbb{E}^{\mathcal{G}}\left[\mathbb{E}^Q\left(\int_0^\tau \frac{D(t)(r(t) - i(t))}{B(t)}dt \mid \mathcal{G}_\tau\right)\right] \\ &=: \mathbb{E}^{\mathcal{G}}\left[V_D^{\mathcal{G}}(0)\right] \ ,\end{aligned} \tag{6}$$

where

$$
\begin{aligned}
&V_D^{\mathcal{G}}(0)\\
&= D(0)e^{-\alpha_2 r(0)}(1-\beta_2)\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}\mathbb{E}^Q\left(r(t)e^{(\alpha_1-1)\int_0^t r(s)ds+\alpha_2 r(t)} \mid \mathcal{G}_\tau\right)dt\\
&+ D(0)e^{-\alpha_2 r(0)}\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}(-i(0)-\beta_0 t+\beta_2 r(0))\mathbb{E}^Q\left(e^{(\alpha_1-1)\int_0^t r(s)ds+\alpha_2 r(t)} \mid \mathcal{G}_\tau\right)dt\\
&- D(0)e^{-\alpha_2 r(0)}\beta_1\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}\mathbb{E}^Q\left(\int_0^t r(s)ds\, e^{(\alpha_1-1)\int_0^t r(s)ds+\alpha_2 r(t)} \mid \mathcal{G}_\tau\right)dt\ .
\end{aligned}
$$

By using the joint distribution of $r(t)$ and $\int_0^t r(s)ds$ in (2) we get

$$
\begin{aligned}
&V_D^{\mathcal{G}}(0)\\
&= D(0)e^{-\alpha_2 r(0)}(1-\beta_2)\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}M(t)\left(\mu_1(t)+S_{1,1}(t)+S_{1,2}(t)(\alpha_1-1)\right)dt\\
&+ D(0)e^{-\alpha_2 r(0)}\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}(-i(0)-\beta_0 t+\beta_2 r(0))M(t)dt\\
&- D(0)e^{-\alpha_2 r(0)}\beta_1\int_0^\tau e^{\alpha_0 t-\alpha_3\int_0^t r^C(s)ds}M(t)(\mu_2(t)+S_{2,2}(t)(\alpha_1-1)+S_{1,2}(t)\alpha_2)dt\ ,
\end{aligned}
\tag{7}
$$

where

$$M(t)=e^{\mu_1(t)\alpha_2+\mu_2(t)(\alpha_1-1)+\left(S_{1,1}(t)(\alpha_2)^2+2S_{1,2}(t)(\alpha_1-1)\alpha_2+S_{2,2}(t)(\alpha_1-1)^2\right)/2}\ .$$

To evaluate deposits, we need to model the dynamics of $r^{DF}(t)$. We follow Renne (2016) assuming that $r^{DF}(t)$ evolves as a continuous-time and discrete space Markov chain. The states and the transition probabilities are derived from the time series of the deposit facility rate. To keep the analysis as simple as possible, we opt for a three-state process for $r^{DF}(t)$: $r_2 > r_1 > r_0 = 0$. Notice that a continuous-time and discrete space Markov chain is always $M^1([0,T])$ because it is a bounded process on $[0,T]$. Hence, we can apply the formula in (6).

As far as the remuneration of CBDC is concerned, we consider three different schemes:

1. $r^c(t) = r^{DF}(t)$
2. $r^c(t) = 0$
3. $r^c(t) = [r^{DF}(t)-k]^+, \quad r_0 < k < r_1$.

Hypothesis 1 and 2 remunerate CBDC as bank reserves and cash, respectively. Hypothesis 3 comes from Bindseil (2020) and Bindseil and Panetta (2020). The remuneration scheme is designed to allow banks to set a deposit rate above that of CBDC limiting disintermediation. A larger k would imply a larger spread for the deposit rate vs. CBDC and less disintermediation.[4]

To compute the value of deposits in (7) we proceed as follows: (i) we simulate N_{sim} paths of $r^{DF}(t)$, (ii) for every path we compute $V_D^{\mathcal{G}}(0)$ as in Eq. (2), (iii) we take the average of the N_{sim} values of $V_D^{\mathcal{G}}(0)$.[5]

5. The dataset and parameters estimation

We calibrate the model parameters for the Euro area and the United States from different data sources.

The deposit volume parameters (α_0, α_1 and α_2) and the deposit rate parameters (β_0, β_1 and β_2) are estimated from the historical monthly time series of deposit market values, deposit rates, and market interest rates available in the ECB statistical data warehouse for the Euro area and the FED database for the US. The time series span from January 2005 to November 2021 for the Euro area and from January 2009 to June 2022 for the US.[6]

As a proxy for the European market interest rate, we consider the EONIA rate[7] for the Euro area and the effective federal fund rate for the US.

For the Euro area and the US we estimate the parameters of deposit volume and deposit rates in (3) and (4) through two linear regressions. In Table 1, we report the results of the regression of $\log(D_t/D_0)$ with respect to time t, the integral of the market interest rate $\int_0^t r(s)ds$ and the market interest rate $r(t)-r(0)$ for the Euro area and the US. Obviously we set $\alpha_3 = 0$ as the CBDC is not already issued.

In Table 2, we report the results of the regression of $i(t)-i(0)$ with respect to time t, the integral of the market interest rate $\int_0^t r(s)ds$ and the market interest rate $r(t)-r(0)$ for the Euro area and the US.

4 Burlon et al. (2022) consider three different remuneration rules: no remuneration, proportional to the deposit facility rate, proportional to the steady state interest rate on reserves.

5 We have conducted extensive numerical experiments considering a time horizon τ up to five years. We can conclude that with $N_{sim} = 10^5$ the value of deposits converges up to the fourth decimal digit.

6 The last months for the US and the Euro area were the last available data at the time of the analysis. We have opted to start the analysis in 2009 for the US because at the end of 2008 the FED decided to change its monetary policy switching from a target rate to a target range.

7 The EONIA rate was substituted by the Euro short-term rate (€STR) plus an 8.5 bps. spread starting from the 2nd of October 2019.

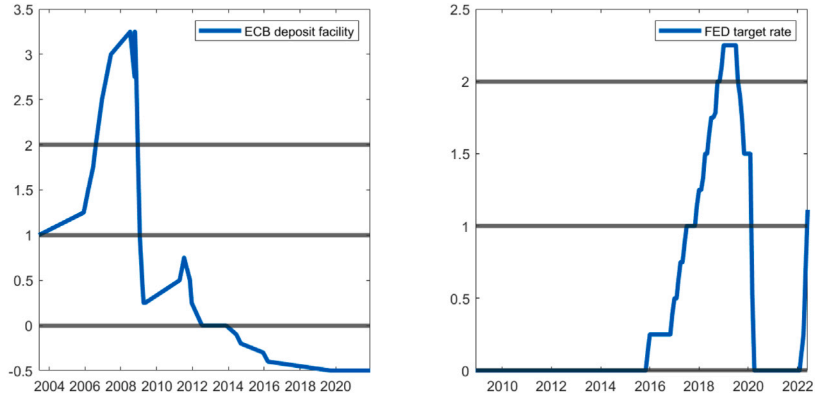

Fig. 1. ECB deposit facility rate (left) and FED target rate (right). The horizontal gray lines identify the three levels of central bank rates for the Markov switching process $r^{DF}(t)$.

Table 1
Estimated parameters of the deposit volume equation for the Euro area and the US.

Parameter	Euro area		US	
	Estimate	p-value	Estimate	p-value
α_0	8.3%	$<10^{-16}$	5.46%	$<10^{-16}$
α_1	−0.41%	$5 * 10^{-8}$	1.99%	$7 * 10^{-6}$
α_2	1.78%	$6 * 10^{-6}$	−5.72%	$<10^{-9}$

Table 2
Estimated parameters of the deposit rate for the Euro area and the US.

Parameter	Euro area		US	
	Estimate	p-value	Estimate	p-value
β_0	−2.8%	$<10^{-16}$	−0.2%	$<10^{-16}$
β_1	1.4%	$<10^{-16}$	21.9%	$<10^{-16}$
β_2	20%	$<10^{-16}$	26.2%	$<10^{-16}$

The linear regressions fit very well the deposit volume (adjusted R^2 above 99%) and the deposit rate (adjusted R^2 above 40%). We apply the Engle–Granger test to check that the deposit rate and the market interest rate time series are not co-integrated (see Engle and Granger, 1987). In both markets, we do not detect statistical evidence to reject the null hypothesis of no co-integration (83% p-value in the Euro area and 13% p-value in the US).

The generator matrices of the Markov switching process $r^{DF}(t)$ are estimated starting from the time series of the ECB deposit facility rate and for the FED target rate (in Fig. 1 we report the two central bank rates). The three integer values of $r^{DF}(t)$ that discretize the observations minimizing the mean square error are $r_0 = 0$, $r_1 = 1\%$ and $r_2 = 2\%$.

We discretize the time series of $r^{DF}(t)$ to these three states, then we estimate the generator matrix Q from the discretized time series allowing for jumps only within adjacent states. The estimated generator matrix is

$$Q = \begin{bmatrix} -0.31 & 0.31 & 0 \\ 0.20 & -0.31 & 0.10 \\ 0 & 0.31 & -0.31 \end{bmatrix}$$

for the Euro area and

$$Q = \begin{bmatrix} -0.38 & 0.38 & 0 \\ 0.19 & -0.38 & 0.19 \\ 0 & 0.38 & -0.38 \end{bmatrix}$$

for the US.

For the third remuneration scheme, we set $k = 0.5$ in such a way that the remuneration of CBDC is null in the first state, 0.5 and 1.5 in the second and third state, respectively.

We evaluate the deposit market value on the 30th of June 2022, with an abuse of notation we set $t = 0$ as that date. At that time the ECB deposit facility rate was −0.5% (state 0) while the lower bound of the FED fund rate was 1.5% (state 2).

The Vasicek model parameters (a, h, and σ) are estimated from cap and floor prices on the six-month Euribor curve for the Euro and the US market. Caps and floors are quoted in terms of implied volatility that we obtain from Eikon Reuters. We calibrate the market interest rate model by minimizing the distance between model and market prices. For a description of interest rate derivatives, caps and floors we refer to Hull (see e.g. 2006, and references therein). A cap is the sum of n caplets with $0 < t_1 < t_2 ... < t_i ... < t_n$ payment dates. Hence, the problem of pricing a cap boils down to pricing the n underlying caplets. The ith caplet price for the extended Vasicek model under the martingale measure is provided in Back (2005, ch.13, Eq. (13).20b):

$$C(t_i) = B(t_i)N(-d_2) + (1 + \bar{R}(t_{i+1} - t_i))B(t_{i+1})N(-d_1) \ ,$$

where $\bar{R}$ is the caplet rate and

$$\begin{aligned} d_1 &:= \frac{log((1 + \bar{R}(t_{i+1} - t_i))B(t_{i+1})) - log(B(t_i)) + \frac{1}{2}\sigma_{avg}^2 t_i}{\sigma_{avg}\sqrt{t_i}} \\ d_2 &:= d_1 - \sigma_{avg}\sqrt{t_i} \\ \sigma_{avg} &:= \frac{\sigma e^{-at_i}\left(1 - e^{-a(t_{i+1}-t_i)}\right)}{a}\sqrt{\frac{e^{2at_i} - 1}{2at_i}} \ . \end{aligned}$$

Notice that the price only depends on the parameters a and σ and not on the long-term rate, and therefore, the stochastic long-term mean does not affect the caplet price. The calibrated parameters on the 30th of June 2022 are $a = 0.05$ and $\sigma = 0.01$ for the Euro area and $a = 0.15$, $\sigma = 0.02$ for the US. The money market rate in the US is characterized by a stronger mean reversion a and a higher volatility σ.

Given the estimated a and σ, we calibrate the parameter h by matching the model zero coupon bond prices ($\mathbb{E}^Q[e^{-\int_0^t r(u)du}]$ for maturity t) and the market implied zero-coupon prices. Thanks to Proposition 1, conditioned to $\mathcal{G}_t$, the bond prices are log-normal with mean $\mu_2(t)$ and variance $S_{2,2}(t)$. Then, we can price the zero coupon bonds following the same approach that we already introduced for $V_D(0)$: (i) we simulate N_{sim} paths of $r^{DF}(t)$ and compute $\mu_2(t)$ and $S_{2,2}(t)$, (ii) for every path we compute the zero coupon bond price as the expected value of the log-normal with mean $\mu_2(t)$ and variance $S_{2,2}(t)$, (iii) we compute the average of the N_{sim} zero coupon bond prices. The calibrated parameters on the 30th of June 2022 are $h = 1.2\%$ in the Euro area and $h = 2.8\%$ for the US.

There are some relevant differences between the Euro and the US market.

As far as the deposit volume is concerned, we observe that the trend component in the Euro area is stronger than in the US, see Table 1. Moreover, we observe a large negative coefficient for the market interest rate in the US and a small positive coefficient in the Euro area. Conversely, there is a small negative coefficient for the integral of the market interest rate in the Euro area and a large positive coefficient in the US. Notice that the market interest rate $r(t)$ positively affects the deposit interest rate $i(t)$ both in the Euro area and in the US, see Table 2. The magnitudo of the relation for the US being higher than for the Euro area. Thanks to this positive relation, the remuneration of deposits ($i(t)$) and the money market rate ($r(t)$), which can be considered as an outside option for depositors, move together and, therefore, the net effect of a change of $r(t)$ on deposit volume can be either positive or negative. In the US market, the overall effect turns out to be negative with an outflow of deposits in case of an increase of the money market rate, instead in the Euro area the effect is positive with an inflow of deposits.

The two markets look quite different. First of all, the money market rate is higher in the US than in the Euro area both at the time of the evaluation of deposits and in the long run (higher h). This results is consistent with the European and US interest rate curves at the time of the analysis. Deposit rates are positively affected by the market interest rate in both markets, however the magnitude of the coefficients in the Euro area is smaller than in the US market. Money market rates show a stronger mean reversion (a) and volatility (σ) in the US than in the Euro area.

The different reaction of deposit to market rates could be explained by the fact that investors in the US are more sensitive to money market conditions than in the Euro area and, therefore, the deposit market is more liquid and less viscous. Although the market rate positively affects the deposit rate in both markets, an increase of the market rate in the US leads to a substitution of deposits with other markets or assets, instead European investors detain more deposits. It is interesting to notice that the effect of the integral of the market rate on the deposit volume is somewhat symmetric to the one of the market rate: an increase in the integral of the market rate leads to a substitution from deposits towards other markets or assets in the Euro area and an increase of deposits in the US. This effect partially balances that of $r(t)$.

6. CBDC and the value of sight deposits

We investigate the loss in deposit market value of banks when a CBDC is introduced in the Euro area and in the US in three steps: considering adoption purely for transactional motivations (CBDC as a new payment instrument), introducing a remuneration scheme for the CBDC, and considering the possibility of a bank-run.

As starting date ($t = 0$ in what follows) we consider 30th of June 2022. The evaluation is performed simulating the deposit facility rate process estimated in Section 5, computing the deposit market value in (5) for every path of the policy rate and then averaging the values.

As a reference, we consider the market value of deposits when the CBDC is not issued over a five-year horizon: $V_D(0)$ is 73 billion Euro (1.38% of the deposit volume) in the Euro area and 1.6 trillion dollars (8.84% of the deposit volume) in the US. The deposit market value as a percentage of the deposit volume in the US is significantly higher than in the Euro area, the rationale being that the US market rate, compared to the deposit rate, is much higher than the Euro area rate at the evaluation date and also in the simulations. As observed in the previous Section, the Euro area and the US market offer two different environments with low and

Table 3

Euro area. Variation of deposit market value over five years with respect to the no CBDC scenario and deposit volume with respect to $D(0)$ after five years (in percentage) for the three scenarios and adoption time ($\hat{T}$) going from 1 to 5 years. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 73$ billion, $\mathbb{E}[D(5)] = 151\%$, without CBDC					
$\hat{T}$	1	2	3	4	5
Adoption scenarios	Delta deposit market value [%]				
Moderate	−2.26	−2.19	−2.06	−1.86	−1.59
Large	−48.96	−47.72	−45.38	−41.79	−36.86
Capped	−12.20	−11.84	−11.15	−10.11	−8.67
	Deposit volume [%]				
Moderate	148.18	148.18	148.18	148.18	148.18
Large	76.99	76.99	76.99	76.99	76.99
Capped	133.01	133.01	133.01	133.01	133.01

high interest rates, respectively. As a consequence, the estimated long term mean of the money market rate in the US is significantly higher than in the Euro area and the difference $r(t) - i(t)$ in (5) is larger than for the Euro area on average: the expected difference between the two rates over five years is 1.2% in the US and 0.24% in the Euro area.

A higher market rate in the US compared to the Euro area results in lower deposit volume increase in the first market, compared to the second one: the expected deposit volume in the US after five years is 146% of the volume in $t = 0$, while deposit volume in the Euro area is at 151%. Despite this mild difference in deposit volume, the effect of the larger interest rate differential prevails leading to the difference in the deposit market value between the two markets.

The first step consists in evaluating CBDC's adoption for a purely transactional motivation. The analysis is accomplished modeling the demand of CBDC (deposit outflow) for payment reasons abstracting from its remuneration (we keep $\alpha_3 = 0$). We introduce a deterministic time dependent outflow of deposit (out) according to the three scenarios described in Adalid et al. (2022, tab.2, p.11):

- *moderate adoption*: substitution of $out = 120$ billion of euro,
- *large adoption*: substitution of $out = 2594$ billion,
- *capped adoption*: substitution of $out = 647$ billion.

The capped adoption scenario coincides with the large adoption scenario plus the constraint that each person cannot hold more than 3000 Euro of CBDC. Note that the outflow refers to households' deposits. As an illustrative analysis, we apply the above scenarios also to US banks by considering the same percentage impact on initial deposits.[8]

To carry out the analysis we set $\psi^c(t)$ in (4) as

$$\psi^c(t) = log(1 - out/D(0)) \min(1, t/\hat{T}) \ ,$$

where $\hat{T}$ is the adoption time and out is the amount of deposits that is substituted by CBDC according to the three scenarios. This function is such that the deposit volume linearly decreases over time in such a way that

$$D(t) = (D(0) - out)e^{\alpha_0 t + \alpha_1 \int_0^t r(s)ds + \alpha_2 (r(t) - r(0)) - \alpha_3 \int_0^t r^C(s)ds} \quad \forall t \geq \hat{T}.$$

Therefore, the volume of deposits after five years (reported in Tables 3 and 4) only depends on the adoption rate scenario (moderate, large or capped) and on the realizations of policy/market rates and not on the adoption time ($\hat{T}$). In our analysis we consider different adoption times: $\hat{T} = 1, 2, 3, 4, 5$. The shorter is the horizon, the quicker will be the adoption of CBDC by households.

In Table 3, we report the percentage variation of deposit market value $V_D(0)$ over five years (delta deposit market value) with respect to the no CBDC scenario and the variation of expected deposit volume with respect to the initial deposit volume $D(0)$ after five years (in percentage) for the three scenarios. In Table 4, we report the same quantities for the US.

The analysis almost shows an insignificant effect of the adoption of CBDC on the value of deposits considering the moderate scenario (around 2% of the deposit market value). The loss is significant only in the large adoption scenario, considering the capped adoption scenario the reduction of the deposit market value is around 10%. The results are similar for the two markets. As expected, the loss in the deposit market value decreases as the adoption time increases.

As a second step, we introduce remuneration of CBDC. We add this feature on top of the deterministic component for transactional motivations considered in the first step. The key parameter is α_3: the coefficient relating the CBDC rate to the deposit volume. In what follows, we evaluate the deposit market value and expected volume for different values of α_3 in the moderate adoption scenario with a five years adoption time ($\hat{T} = 5$). In Table 5, we report the variation of the deposit market value $V_D(0)$ over five years with respect to the no CBDC scenario and the expected deposit volume with respect to the initial level $D(0)$ after five years (in percentage) for the three remuneration schemes in the Euro area. In Table 6, we report the results for the US market.

Considering the second remuneration scheme ($r^c(t) = 0$), CBDC is like cash and therefore the same values are obtained for all values of α_3. We can consider this remuneration scheme as the central scenario only dealing with the deterministic outflow of

[8] As far as we know, there is no study quantifying the impact of CBDC adoption on US deposits.

Table 4
United states. Variation of deposit market value with respect to the no CBDC scenario over five years and deposit volume with respect to $D(0)$ after five years (in percentage) for the three scenarios and adoption time ($\hat{T}$) going from 1 to 5 years. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 1.6$ trillion, $\mathbb{E}[D(5)] = 146\%$, without CBDC,					
$\hat{T}$	1	2	3	4	5
Adoption scenarios	Delta deposit market value [%]				
Moderate	−2.13	−1.96	−1.75	−1.53	−1.28
Large	−46.45	−43.15	−39.35	−35.10	−30.46
Capped	−11.51	−10.59	−9.53	−8.34	−7.04
	Deposit volume [%]				
Moderate	143.04	143.04	143.04	143.04	143.04
Large	74.32	74.32	74.32	74.32	74.32
Capped	128.40	128.40	128.40	128.40	128.40

Table 5
Euro area. Variation of deposit market value over five years with respect to the no CBDC scenario and deposit volume with respect to $D(0)$ after five years (in percentage) for the three different CBDC remuneration schemes in the moderate adoption scenario, $\hat{T} = 5$ and different values of α_3. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 73$ billion, $\mathbb{E}[D(5)] = 151\%$, without CBDC								
$\alpha_3(\%)$	−2	−1	0	1	2	3	4	5
	Delta deposit market value [%]							
$r^c = r^{DF}$	1.63	0.00	−1.59	−3.12	−4.60	−6.04	−7.44	−8.79
$r^c = 0$	−1.59	−1.59	−1.59	−1.59	−1.59	−1.59	−1.59	−1.59
$r^c = max(r^{DF} - k, 0)$	0.18	−0.71	−1.59	−2.44	−3.28	−4.10	−4.90	−5.69
	Deposit volume [%]							
$r^c = r^{DF}$	154.96	151.50	148.18	144.99	141.93	138.98	136.14	133.41
$r^c = 0$	148.18	148.18	148.18	148.18	148.18	148.18	148.18	148.18
$r^c = max(r^{DF} - k, 0)$	151.88	150.01	148.18	146.40	144.67	142.97	141.32	139.70

deposits due to adoption of CBDC for transactional reasons. For this scheme, the market value of deposits reduces by 1.59% and 1.28% with respect to the no issuance of CBDC for the Euro area and the US market, respectively (data coincide with those reported in Tables 3 and 4). These values are also reported for the other remuneration schemes when $\alpha_3 = 0$.

The results on the deposit market value are strictly linked to the evolution of deposit volume. Notice that the contribution of remuneration of CBDC to deposit volume in (4) is the integral of a positive quantity (remuneration of CBDC) multiplied by $-\alpha_3$. Therefore, a positive (negative) α_3 leads to a lower (higher) deposit volume with respect to the case analyzed in Tables 3 and 4. This effect leads to a decrease (increase) in the deposit market value with respect to the no remuneration setting. The larger effect in the US is due to the fact that r^{DF}, that directly impacts the remuneration of CBDC and hence the deposit volume, is expected to be higher than in the Euro area in the near future. At the time of the analysis, the expected average policy rate over five years is 1% in the US and 0.44% in the Euro area. The difference in the effects of remuneration in the two markets can be evaluated considering $\alpha_3 = 2$, a value similar to α_2 in (4) for the Euro area. The first remuneration scheme ($r^c(t) = r^{DF}(t)$) leads to the highest reduction in the deposit market value: −4.60% and −6.70% for the Euro area and the US, respectively. The third remuneration scheme ($r^c(t) = [r^{DF}(t) - k]^+$) induces a smaller effect: −3.28% and −4.51% for the deposit market value of the Euro area and the US, respectively.

Similar results hold true for the other adoption rate scenarios. The negative impact of remuneration of CBDC on deposit market value with respect to the no remuneration case ($r^c = 0$) decreases as the outflow increases, i.e., it decreases as we consider the capped and then the large adoption scenario.

In Table 7, we report the variation in the deposit market value considering the three different adoption scenarios and the three remuneration schemes with $\alpha_3 = 2$ and $\hat{T} = 5$. In the Euro area, we observe that the deposit value variation with the first remuneration scheme is around −3% in the moderate adoption scenario and around −2% for the large adoption scenario with respect to the reduction observed in the no remuneration case, which is reported for the second remuneration scheme. Similarly, in the US the deposit market value with the first remuneration scheme decreases by around 5.4% for the moderate adoption and around 3.5% for the large adoption scenario. The results for the capped scenario are intermediate. Overall, the remuneration of CBDC induces a small decrease in the market value of deposits compared to the no remuneration setting.

We finally introduce the possibility of a bank-run focusing on the Euro area. We estimate the impact of a bank-run on deposit volume building on the European debt crisis experience. The crisis spanned from January 2010 to December 2012, i.e., for three years.

We consider both the adoption of CBDC due to transactional reasons (ψ^c) and remuneration (we set $\alpha_3 = 2\%$). Introducing the possibility of a bank-run, deposit volume in (5) becomes:

$$D(t) = D(0)e^{\alpha_0 t + \alpha_1 \int_0^t r(s)ds + \alpha_2 (r(t) - r(0)) - \alpha_3 \int_0^t r^C(s)ds - \psi^c(t) - \alpha_4 \phi(t)}, \tag{8}$$

Table 6
United states. Variation of deposit market value over five years with respect to the no CBDC scenario and deposit volume with respect to $D(0)$ after five years (in percentage) for the three different CBDC remuneration schemes in the moderate adoption scenario for $\hat{T} = 5$ and different values of α_3. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 1.6$ trillion, $\mathbb{E}[D(5)] = 146\%$, without CBDC								
$\alpha_3(\%)$	−2	−1	0	1	2	3	4	5
	Delta deposit market value [%]							
$r^c = r^{DF}$	4.61	1.60	−1.28	−4.05	−6.70	−9.25	−11.69	−14.04
$r^c = 0$	−1.28	−1.28	−1.28	−1.28	−1.28	−1.28	−1.28	−1.28
$r^c = max(r^{DF} - k, 0)$	2.13	0.40	−1.28	−2.92	−4.51	−6.06	−7.57	−9.03
	Deposit volume [%]							
$r^c = r^{DF}$	158.40	150.49	143.04	136.02	129.41	123.18	117.30	111.75
$r^c = 0$	143.04	143.04	143.04	143.04	143.04	143.04	143.04	143.04
$r^c = max(r^{DF} - k, 0)$	151.95	147.41	143.04	138.84	134.80	130.92	127.18	123.58

Table 7
Variation of deposit market value over five years with respect to the no CBDC scenario after five years (in percentage) for the three remuneration schemes, $\hat{T} = 5$ and $\alpha_3 = 2$. The values are computed as the average over 10^5 simulation paths for the rates.

Adoption scenario	$V_D(0)$ without CBDC = 73 billion, Euro area		
	$r^c = r^{DF}$	$r^c = 0$	$r^c = max(r^{DF} - k, 0)$
Moderate	−4.60	−1.59	−3.28
Large	−38.66	−36.86	−37.87
Capped	−11.44	−8.67	−10.22
Adoption scenario	$V_D(0)$ without CBDC = 1.6 trillion, US		
	$r^c = r^{DF}$	$r^c = 0$	$r^c = max(r^{DF} - k, 0)$
Moderate	−6.70	−1.28	−4.51
Large	−34.02	−30.46	−32.61
Capped	−12.18	−7.04	−10.15

where

$$\phi(t) := \begin{cases} (\xi - t) & \text{if} \quad \xi < t < \xi + 1 \\ 1 & \text{if} \quad \xi + 1 < t < \xi + 3 \\ 1 - 1/3(t - \xi) & \text{if} \quad \xi + 3 < t < \xi + 6 \\ 0 & \text{otherwhise} \end{cases} .$$

This function reproduces the effect on the Greek deposit time series during the sovereign debt crisis: a sharp decline of deposit volume in 2010, a plateau of two years and then a slow recovery of three years.

We estimate α_4 through a linear regression from the Greek and the Euro area deposit volume time series assuming that the crisis starts in 2010, i.e., we estimate the log-deposit volume linear regression in (8) adding $\phi(t)$ for the crisis period to estimate the parameter α_4. The Greek and the Euro area experiences provide two examples of a severe bank-run and of a mild slow-down of deposit volume, respectively. As observed in Bindseil (2020), the run on bank deposits in favor of cash during the Euro crisis was limited compared to the run towards deposits of other banks and non-bank deposits. The two time series render the following estimates: $\alpha_4 = 17\%$ in the Greek case and $\alpha_4 = 6.5\%$ in the Euro area case. In Fig. 2, we plot the logarithm of deposit volume in Greece and the Euro area realized (in blue) and fitted values when a three-year bank-run starting in 2010 is introduced and modeled as above (in red). The dashed black line corresponds to the period in which the bank-run affects the deposit volume.

We quantify the impact of CBDC on a bank-run following Adalid et al. (2022, cf. chart 13) considering the case of no issuance of CBDC, a moderate adoption and a large adoption scenario. They argue that the effect of a bank-run can be enhanced by the presence of the CBDC and estimate the severity of a bank-run to be 4/3 and 3 times the no CBDC case in case of a large adoption and moderate adoption scenario, respectively. In what follows, we follow the same approach. The analysis is performed for the first remuneration scheme, $\alpha_3 = 2$ and $\hat{T} = 5$. The possibility of a bank-run has similar effects for the other remuneration schemes.

In Table 8, we report the variation of deposit market value with respect to the no CBDC scenario and the deposit volume with respect to the initial deposit volume (in percentage) after five years for the Euro area when α_4 is calibrated on the Greek bank-run.

In the simulations we model a bank-run through an exponential random variable ξ with parameter λ independent from the market rate and the deposit facility rate. The realization of the random variable ξ represents the time at which the bank-run is triggered. We recall that, for an exponential random variable, the probability of a crisis before time $\hat{\xi}$ is $1 - exp^{-\lambda\hat{\xi}}$. We consider different values of λ varying the bank-run probability over five years. The variation of deposit market value due to the issuance of CBDC with respect to the no bank-run/no CBDC setting are shown in Table 7. We recall that the five-year expected value of deposit is 73 billion (1.38% of the deposit market value) in the no CBDC/no bank-run scenario. We may consider the 5% probability of a bank-run in the next five years as a reference.

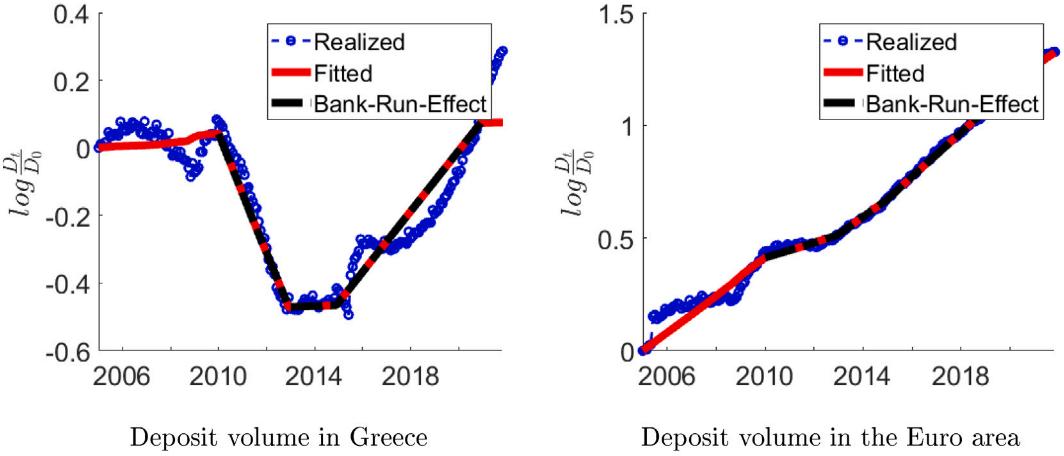

Fig. 2. Logarithm of the deposit volume for Greece and the Euro area, realized (in blue) and fitted (in red) values when a bank-run is modeled starting in 2010. The dashed black line corresponds to the period in which the bank-run term affects the deposit volume. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 8

Euro area. Variation of deposit market value over five years with respect to the no CBDC scenario and deposit volume with respect to $D(0)$ after five years (in percentage) for the two adoption scenarios when a bank-run, calibrated on the Greek bank-run, may occur. λ varies between 0 and 0.1, the probability of bank-run varies accordingly, $\hat{T} = 5$ and $\alpha_3 = 2\%$. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 73$ billion, $\mathbb{E}[D(5)] = 151$ without CBDC						
λ	0	10^{-3}	0.01	0.02	0.05	0.10
Prob	0	0.01	0.05	0.10	0.22	0.39
	Delta deposit market value [%]					
No CBDC	0	−0.08	−0.88	−1.74	−4.16	−7.70
Large adoption	−38.66	−38.72	−39.29	−39.90	−41.62	−44.15
Moderate adoption	−4.60	−4.76	−6.38	−8.13	−13.00	−20.11
	Deposit volume [%]					
No CBDC	151.63	151.43	149.38	147.28	141.37	132.84
Large adoption	73.74	73.61	72.37	71.10	67.52	62.35
Moderate adoption	141.93	141.53	137.56	133.53	122.17	105.79

In case of no issuance of CBDC, the deposit market value decreases by 88 basis points because of the possibility of a bank-run. In the large and moderate adoption scenarios, the value of deposit decreases by 60 (39.26-38.66) and 180 (6.38-4.60) basis points, respectively, because of the possibility of a bank run . The second column in Table 8 ($\lambda = 0$) reports the case with zero probability of bank-run providing us with the benchmark (results are those reported in Table 7).

In Table 9, we report the same analysis when the bank-run is calibrated on the Euro area deposit time series. As expected, the bank-run effect is smaller compared to the severe bank run scenario: 20 and 65 basis points in the large and moderate adoption scenarios, respectively. Notice that, in this framework, monetary policy (i.e. the central bank rate) is independent from the bank-run phenomenon. We point out that this is a conservative assumption. As an additional exercise, we run the model assuming that the central bank lowers rates (i.e. the long term mean to the state 0) in the case of a bank run. As we expected, an accommodative monetary policy reduces further the already small effect of a bank-run, but the effect is limited: with a 5% probability of a bank-run, the decrease in deposit value in a moderate take-up scenario is −4.75% instead of −4.76% and in a large adoption scenario is −39.19% instead −39.29%.

We can conclude that a bank-run does not significantly affect the market value of deposits for banks in case the CBDC is issued.

7. Conclusions

Although practitioners are expecting the issuance of CBDC as soon as possible, central banks are cautious on the topic. The main reason being that its design may significantly affect financial intermediation as CBDC would directly compete with deposits putting at risk the role of banks.

There are some attempts to estimate the effects of CBDC on banks' balance sheets pointing out that it should be small. In this paper we have provided the first market-based analysis showing how CBDC issuance would affect the market value of deposits in the Euro area and in the US at the aggregate level. We have shown that the effect would be small unless the extreme scenario of a large adoption rate materializes. In case of a massive adoption of CBDC, the reduction of the value of deposits would be between

Table 9
Euro area. Variation of deposit market value over five years with respect to the no CBDC scenario and deposit volume with respect to $D(0)$ after five years (in percentage) for the two adoption scenarios when a bank-run calibrated on the Euro area bank-run may occur. λ varies between 0 and 0.1, the probability of bank-run varies accordingly, $\hat{T} = 5$ and $\alpha_3 = 2\%$. The values are computed as the average over 10^5 simulation paths for the rates.

$V_D(0) = 73$ billion, $\mathbb{E}[D(5)] = 151$, without CBDC						
λ	0	10^{-3}	0.01	0.02	0.05	0.10
Prob	0	0.01	0.05	0.10	0.22	0.39
	Delta deposit market value [%]					
No CBDC	0	−0.02	−0.25	−0.50	−1.20	−2.22
Large adoption	−38.66	−38.68	−38.85	−39.04	−39.55	−40.31
Moderate adoption	−4.60	−4.66	−5.25	−5.89	−7.68	−10.31
	Deposit volume [%]					
No CBDC	151.63	151.57	150.98	150.36	148.63	146.14
Large adoption	73.74	73.70	73.32	72.93	71.83	70.24
Moderate adoption	141.93	141.78	140.27	138.72	134.37	128.08

30% and 50%, otherwise the loss for the banking system would be smaller than 10%. We have also shed light on two features of CBDC: its remuneration and its role in amplifying a bank-run. The remuneration scheme plays a significant role only in the moderate/capped adoption scenario in relative terms and in a high interest rate environment. The analysis provides a clear ranking among the remuneration schemes under discussion: the lowest loss in the deposit market value is obtained in case of no remuneration (CBDC like cash), the highest loss is obtained in case of a CBDC remunerated as bank reserves, the option based remuneration scheme proposed in Bindseil (2020) and Bindseil and Panetta (2020) lies in the middle allowing banks to limit disintermediation. The possibility of a bank-run calibrated on the experience of the Euro area and of Greece during the debt crisis has a limited effect on the value of deposits. Overall, we can conclude that the CBDC is not a real threat for financial stability of banks.

CRediT authorship contribution statement

Michele Azzone: Concept, Design, Analysis, Writing, Revision of the manuscript. **Emilio Barucci:** Concept, Design, Analysis, Writing, Revision of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Generative AI

The authors declare that they have not used any type of generative artificial intelligence for the writing of this manuscript, nor for the creation of images, graphics, tables, or their corresponding captions.

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