The Impact of CBDC on a Deposit-dependent Banking System *

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In this paper, we examine the implications of a central bank digital currency (CBDC) for banks particularly dependent on customer deposits for their business model. We hand-collect customer data from savings and cooperative banks in Germany to determine conversion rates of customer deposits to a CBDC. We show that even at low conversion rates, over one-third of German savings and cooperative banks do not have enough excess reserves at the central bank to balance the CBDC conversion. Furthermore, we show that small banks, in particular, face hurdles when introducing a CBDC and must refinance themselves on the interbank market or through the central bank. This refinancing has implications for these banks' liquidity and hence stability and reduces their profitability, as low-interest customer deposits are exchanged for higher-interest interbank loans. Our results are relevant for commercial banks, as they help better assess the impact of a CBDC on liquidity and profitability, and for central banks, as we find a lower bound on banks' costs of a CBDC implementation.

Keywords: Central Bank Digital Currency, Digital Money, Banking, Interbank Market, Intermediation
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1 Introduction

The importance of cash in daily payment transactions is declining rapidly in many industrialized countries (Khiaonarong and Humphrey, 2019), while the adoption of electronic means of payments has proliferated in recent years (Burlon et al., 2022). In addition, the increasing popularity of cryptocurrencies as stores of value and potential payment instruments and the accompanying loss of monetary power force policymakers to act (Makarov and Schoar, 2021). Currently, most central banks are examining the issuance of digital currencies[1] as an alternative to physical cash to prevent further crowding out by private issuers in the future (Hemingway, 2022; Brunnermeier and Niepelt, 2019). Because CBDCs are primarily at the policy consultation stage, the literature is based predominantly on theoretical models, hypothetical scenarios, and assumptions subjected to debate (Whited et al., 2022; Bindseil, 2020). If a CBDC is introduced, commercial banks must deal with disintermediation effects due to the potential loss of private deposits in favor of central bank liabilities (Chiu et al., 2021). Our paper contributes to the literature by examining these effects empirically.

In this paper, we analyze the impact of a CBDC introduction on banks that rely heavily on customer deposits due to their traditional savings and loan business. We use the balance sheet information of individual retail banks and analyze the disintermediation effects of a CBDC. To our best knowledge, we are the first to do so in more detail, examining changes in balance sheet items and highlighting differences across banks empirically. Our take-up scenarios build on a hand-collected number of current accounts and customers to determine an accurate CBDC conversion rate of current deposits into a CBDC at the bank level. We apply these conversion rates to model the outflow of customer deposits on banks' balance sheets and point out consequences for liquidity, refinancing, and profitability. Therefore, we contribute to the ongoing discussion on quantifying possible allocative disadvantages of CBDC-induced bank disintermediation (e.g., see Burlon et al., 2022).

Our empirical results show that even at low CBDC conversion rates, one-third of the customer deposit-dependent banks do not have enough (excess) central bank reserves to

1. For an up-to-date status, see https://cbdctracker.org/

compensate for the deposit outflow. As a result, these banks need to refinance via the interbank market or the central bank itself, leading to lower overall liquidity, higher interest costs, and lower profitability. We argue that these additional costs may act as a floor to determine central banks' financial compensation to banks.

In the summer of 2021, the ECB Governing Council officially decided to start the digital euro project investigation phase. At the end of 2023, the Eurosystem will decide to move into the realization phase and develop the technical framework for a European CBDC (Balz, 2022). Uncertainty about the specific design of CBDCs and lack of experience with expected demand in advanced economies make estimating its impact a major challenge for scholars (Adalid et al., 2022). We contribute to the emerging literature strand by framing a CBDC close to the (potential) digital euro using information from statements of public authorities and creating withdrawal scenarios derived from customer and account information.

We use balance sheet and income statement data of German banks, whose business profiles represent a pronounced dependence on deposits. Our sample comprises a comprehensive data set of recent balance sheets of 1,172 savings and cooperative banks. These typically small and unlisted financial institutions together hold 45% of all national retail deposits and are responsible for granting almost half of the German banking sector's total loans to households and firms (Deutsche Bundesbank, 2021). Moreover, their regional customer deposit business is essential for both banking groups (Fecht et al., 2019), as the reliably low remuneration of current deposits accounts for a significant portion of the net interest income of these banks and compensates for retail customers' payment and liquidity services (Busch and Memmel, 2021).

The emerging theoretical literature studying the effect of introducing a CBDC focuses on the effects on the banking sector, monetary policy mechanisms, and financial stability (Carapella and Flemming, 2020). Many recent studies use an overall picture approach (Chen and Siklos, 2022), explaining the economic and financial interactions of private banks, governments, central banks, and households concerning varying forms of CBDC (e.g. Bordo et al., 2018; Davoodalhosseini and Rivadeneyra, 2018). Concrete theoretical guidance on specific implications of CBDC adoption for policymakers is scarce (Chen and

Siklos, 2022). Andolfatto (2021) sets up a macroeconomic model with a monopolistic deposit market and adds an interest-bearing CBDC, which increases competition in the deposit market, resulting in higher deposit remuneration in equilibrium and reducing the monopolist's profit. As long as banks can borrow and store central bank reserves at the same interest rate, a reduction in bank lending may be ruled out. A related study of Chiu et al. (2021) develops a general equilibrium model but, for a more appropriate application, assumes a spectrum of competition and an imperfect substitution of cash, deposits, and CBDC. They test the effects of a hypothetical CBDC introduction in the United States and confirm an improvement of bank intermediation also in the case of a non-interest-bearing CBDC if the decline in cash payments continues. Brunnermeier and Niepelt (2019) use a generic model of money and liquidity and confirm that in a widely frictionless financial system, central banks can implement a CBDC without impacting banks' intermediation capability by lending back to commercial banks. Fernández-Villaverde et al. (2021) benchmark an economy on the banking model of Diamond and Dybvig (1983) and show that, under certain assumptions in normal times, allocations achieved with private financial intermediation are also reached with a CBDC. However, a CBDC would erode depository funds available to commercial banks. Applying the same canonical banking model, Schilling et al. (2020) demonstrate that the central bank may reduce the probability of a bank run on CBDC[2], but faces a so-called CBDC trilemma in the end. The three goals of efficiency, financial stability (especially the prevention of a bank run), and price stability might not be pursued simultaneously.

The literature points out numerous advantages of a CBDC, which are mostly limited to further factors or preconditions that are controversially discussed (see Bindseil, 2020; Mancini-Griffoli et al., 2018). However, due to several frictions like liquidity regulation, lagged mobilization of eligible collateral and securities, and an uneven distribution of central bank reserves between and within banking groups, a CBDC could indeed have implications for financial stability (Adalid et al., 2022). Juks (2018) examines the impact of a CBDC introduction using the Swedish banking sector as an example to illustrate

2. Authors like Mersch (2018) and Callesen (2017) denounce the destabilizing effect of CBDCs in future systematic banking crises, as they could accelerate a sector-wide run on bank deposits as an interchangeable risk-free alternative.

the consequences of a fixed outflow of customer deposits into an e-krona. The aggregated balance sheet of the commercial banking sector shows a negative impact on banks' profitability. Banks' funding costs rise because the cheap funding via current deposits vanishes, and banks must take up loans at the central bank or issue more long-term market funding. However, overall financial stability is not threatened in normal times. Bindseil (2020) transmits these mechanisms of an increase in the cost of funding on the aggregate financial account of commercial banks in the euro area and demonstrates the need for the central bank to offset the exacerbating of financial conditions. Adalid et al. (2022) illustrate how several scenarios of deposit outflows are covered by funding sources in the Eurosystem. Furthermore, the authors point out that effects vary across different banking groups in regular times and are even larger in crisis times due to various business models, reliance on deposits, and prone to funding structures. Methodically, we follow a stylized balance sheet approach and contribute to the corresponding literature strand by modeling CBDC-induced changes at the bank level in non-stressed times.

Our results are relevant for commercial banks, central banks, and regulators. Commercial banks are currently confronted with the exogenous decision of their central bank to introduce a CBDC without knowing the exact effects on their business model. Our results can help to better understand the dimensions, as we show the consequences of a CBDC introduction for a bank's liquidity and profitability with easy-to-interpret ratios. About 86% of all central banks are engaged in work with CBDCs (Boar and Wehrli, 2021), but so far, a CBDC has only been introduced and tested in smaller economies, like the Bahamas in 2020, Nigeria in 2021, and Jamaica in 2022 (Atlantic Council, 2022). Thus, central banks in larger currency areas lack adequate data to assess the consequences for price stability, the economy, and banking stability. We help central banks and regulators to quantify the costs of a CBDC in a mainly deposit-based banking system and identify a lower bound for compensatory measures that may have to be made by the central bank to commercial banks. Moreover, our approach is easily transferable to other banking systems.

The structure of the paper is as follows. In Section 2, we discuss possible configurations of a CBDC in Europe based on the digital euro and the potential impact on commercial banks' balance sheets. Section 3 presents our data sources and the process for calculating

conversion rates from customer deposits to CBDC. In Section 4, we introduce our method for changing bank balance sheets and present our results. Section 5 concludes.

2 Background on CBDC

In the wake of the rapid growth of dissemination and value of popular cryptocurrencies, such as Bitcoin or Ethereum, public interest in their recognition as legal tender has increased as well (Makarov and Schoar, 2021). The term cryptocurrency refers to a digital asset that uses blockchain or distributed ledger technology to facilitate a safe transmission.[3] Private entities issuing digital currencies pegged the coins' value to official currencies in an attempt to reduce the typical price volatility of "classic" cryptocurrencies; these are called stablecoins. However, even with sustained stabilization, legal risks, missing consumer protection, and data privacy issues for potential users remain (Group of Thirty, 2022). Nevertheless, the dangerous potential of cryptocurrencies and stablecoins in the hands of a few private players has put pressure on public authorities to regulate them and consider their own digital currency offerings (Balz, 2022).

The term "central bank digital currency" is not uniformly defined but usually refers to a new form of central bank-issued digital money apart from traditional reserves or settlement accounts. Balances in reserve accounts of central banks and common commercial bank money are account-based payment systems and depend critically on verifying the authorized account holder. Apart from that, token-based payment systems like cash and most digital currencies fundamentally rely on the continuous verification of the payment object itself (Löber and Houben, 2018). For further classification purposes, the comprehensive taxonomy of the authors Bech and Garatt (2017) has become established, differentiating between two forms of token-based CBDCs. The two versions differ in terms of access. The first form is only intended for the wholesale segment of large-value and high-priority

3. Several cryptocurrencies represent different forms of tokens, but other assets or rights can be tokenized too. For a detailed outline of the often misunderstood mechanics behind cryptocurrencies, see Härdle et al. (2020).

transactions. The second form is for low-value transactions, generally in the retail segment (Löber and Houben, 2018).

Comparable to the current form of central bank reserves, wholesale CBDCs will only be accessible to particular financial institutions. Monetary authorities in Canada, Singapore, Japan, and Europe have already instigated scattered experiments on wholesale CBDCs (Parlour et al., 2022). The main arguments for implementing distributed ledger technology for interbank transactions are potentially reduced operational costs, less binding of collateral, and liquidity with more security at the same time. This form of CBDC may substantially reduce settlement costs due to the constantly evolving underlying technology, but the utilization framework resembles the current one concerning operational and safety requirements (Löber and Houben, 2018).

The introduction of a CBDC for the general public may represent an important innovation in the history of banking. It allows central banks to be in direct contact with customers by holding their deposits on their balance sheets. Against the backdrop of changing payment habits in favor of cashless transactions (Löber and Houben, 2018), this retail CBDC has a high potential to displace cash (Fernández-Villaverde et al., 2021). Therefore, researchers are unsure at this stage whether and in what proportion a retail CBDC will coexist with cash and deposits. The first test implementation projects by central banks are the e-krona in Sweden and the e-peso in Uruguay (Parlour et al., 2022).

Our paper focuses on the planned introduction of the digital euro and the consequences for the German banking system, especially on the vast majority of retail banks. So far, the authorities have provided only a few general conditions, from which we derive the following assumptions for our model:

- The digital euro intends to supplement—not replace—cash as a legally legitimate means of digital payment available to the broad public (Balz, 2022). Up to a possible ceiling (see below), balances will not be treated less appreciatively than cash (Panetta, 2021). Therefore, we assume a *non-interest-bearing retail CBDC*.

- The digital euro shall be an attractive transaction medium and not be misappropriated for investment purposes or as a repository in the run-up of crisis (Balz, 2022).

Furthermore, to counteract sudden shifts into central bank money, ECB Executive Board member Fabio Panetta has considered *an upper limit per private individual of €3,000*, which we include in our model.

- The operating of digital euro accounts will be outsourced to banks and fintech. Nevertheless, the digital euro will be a liability to the Eurosystem, and *deposits exchanged for CBDC will disappear from banks' balance sheets* (Panetta, 2021).

The overarching purpose of implementing a CBDC is to guarantee citizens access to the most secure form of money within a digitalized economy—central bank money (Burlon et al., 2022). The biggest hurdle to implementation in the current financial system is the threat of disintermediation through the withdrawal of commercial bank deposits (Dombret and Wünsch, 2022). Continued lower demand for bank deposits could lead to a domino effect with less provision of credit to the real sector, increased risk disposition, and overall lower resilience of the banking industry in crisis scenarios. In the following, we illustrate different channels through which commercial banks' balance sheet items would change when a CBDC is put into circulation (Adalid et al., 2022). When households want to swap their cash for CBDC, the procedure appears uncontroversial as the bank simply substitutes one form of central bank money (banknotes) with another one (CBDC) (Bindseil, 2020). If customers want to substitute deposits on their current accounts for CBDC, banks must buy them from the national central bank and can pay with their (excess) reserves or return bank notes. This scenario represents a balance sheet contraction because both cash and central bank reserves (asset side) as well as customer deposits (liability side) shrink.

Commercial banks			
Cash & Reserves	↓	↓	Current deposits

If customers' demand for CBDC exceeds a bank's central bank reserves, affected institutes can widen their interbank borrowings, given that aggregated customers demand strikes differently across banking groups (Adalid et al., 2022). Alternatively, the central bank must fill the funding gap and provide additional reserves to these banks to serve the demand for CBDC in the economy (Bindseil, 2020). This will result in an exchange

of banks' funding profiles, and precisely, customer deposits will be replaced by the central bank or interbank borrowing on the liability side, respectively. The bank needs to pledge high-quality liquid assets for secured funding from the repo market, which is usually cheaper than unsecured funding. Central bank funding has less strict collateral constraints and may also be secured by non-high liquid assets (Adalid et al., 2022). Nevertheless, the bank encumbers parts of its liquid assets, which still remain on the balance sheet but can no longer compensate for future liquidity bottlenecks.

Commercial Banks			
Unencumbered Securities	$^*\downarrow$	$\downarrow$	Current deposits
		$\uparrow$	Interbank / Central bank credit

**remain on balance sheet*

Another option for banks to receive additional reserves is selling assets, especially government and corporate bonds, to the central bank system (Bindseil, 2020). In this case, banks' deposit outflow goes along with a diminution of banks' security portfolios.

Commercial banks			
Securities	$\downarrow$	$\downarrow$	Current deposits

Concerning the digital euro, the European central bank has already considered offering lending via additional refinancing operations to institutes that lose customer deposits due to CBCD transactions (European Central Bank, 2020). Therefore, we assume that *the sale of assets, like securities, will not be necessary* in the first place.

3 Data sources and sample selection

This chapter describes our data sources and explains our variable selection. We derive balance sheet and profit and loss account information from the database *Fitch Connect*. To exclude merged institutions in the later period under review, we manually selected savings banks and cooperative banks from the sector *Retail & Consumer Banks* in Germany with

available balance sheet records in the year 2020. After adjusting for institutions that differ from the rest of their peers in their business model,[4] the sample comprises 376 savings and 796 cooperative banks, covering the entire savings banks sector and almost the whole cooperative banking sector in Germany in 2020. We built our final sample based on annual financial statements for these 1,172 banks from 2018 until 2020. To reduce bias due to outliers in individual years (e.g., the Covid-19 pandemic), we average each bank's individual balance sheet items over these three years.

We extend our data set with the ECB's marginal lending rate. In addition, because information on deposit remuneration at the customer- or bank-level is not available, we also add average interest rates on overnight deposits of private households from the Deutsche Bundesbank.

In Table 1, we give summary statistics for the positions on bank balance sheets that change with CBDC adoption according to our description in Chapter 2 (Juks, 2018; Bindseil, 2020; Fernández-Villaverde et al., 2021).

Table 1 about here.

Due to the persistently low-interest rates in recent years, customers have increasingly converted their long-term deposits into demand deposits. While current deposits accounted for around 43.5% of total customer deposits in 2010 (Deutscher Sparkassen und Giroverband (DSGV), 2010; Bundesverband Deutscher Volksbanken und Raiffeisenbanken (BVR), 2010), this share has risen to over 70% in 2020 (see Table 1). On the one hand, this is advantageous for banks, as demand deposits earn lower interest rates than longer-term investments, but on the other hand, customers can also easily withdraw or convert them.

Although we only look at savings and cooperative banks operating in restricted local regions and are therefore limited in size, we still have strong outliers upwards and downwards in balance sheet items. In particular, large banks such as the Hamburger Savings Bank and the Berliner Cooperative Bank distort the average values. Table 2 and Table 3 show the statistics separately by banking group. One finds that savings banks are, on

4. This concerns umbrella organizations as well as, for example, credit cooperatives with a limited focus on certain professional groups or social projects.

average and in the outliers, larger than cooperative banks. In particular, cash reserves and central bank deposits, which account for 3.22% of total assets at cooperative banks, are comparatively smaller than at savings banks, which hold an average of 6.87% of their total assets in cash, and at the central bank. We will see that especially small cooperative banks face problems in case of a CBDC implementation.

Table 2 about here.

Table 3 about here.

The magnitude of a CBDC introduction on financial intermediaries, especially commercial banks, depends on the predicted demand by the public. Since no advanced economy has implemented a CBDC, researchers have focused on estimating the share of CBDC in circulation based on theoretical models (Burlon et al., 2022). Other studies have conducted surveys on respondents' preferences for opening a CBDC account and using it for retail payments (e.g., see Abramova et al., 2022; Bijlsma et al., 2021). Finally, researchers use different conversion rate assumptions and model several impact scenarios of implementation using aggregated balance sheet data (Adalid et al., 2022). For the latter, detailed information on current accounts, volumes of deposits, and their distribution among different groups of credit institutions are conducive to estimating the adjustment mechanisms mentioned above.

Introducing a digital euro will allow each banking customer to convert a portion of their current deposits and banknotes into digital euros to be able to make payments with the new CBDC. The amount will depend on the personal attitude, the general usage rate, and the possibilities of paying with the CBDC (Juks, 2018; Adalid et al., 2022; Bindseil, 2020).

To determine the losses of customer deposits soundly, we have collected data on the number of bank customers in our data set by hand. Because there are no well-founded results on people's usage behavior so far, we conduct our analyses for different scenarios. First, we assume that each customer converts either €500, €1,000, or €1,500 of their deposits into digital euros. These values are based on the announcement that the digital euro is to be seen as a pure medium of payment and will have an upper limit for holding

(of probably €3,000) and some evidence from user surveys (Abramova et al., 2022; Adalid et al., 2022). We are able to find data on the number of customers or private checking accounts from 2020 for 270 of the 1,172 banks in annual reports, management reports, or on institutes' homepages. We calculate the corresponding usage rate for each of the 270 banks for the three conversion amounts. As can be seen in Table 4, most of the values for within a conversion amount are comparatively close to each other, so we transfer the respective mean value as the usage rate of a digital euro in percentages to each banks' total current deposits in our data set.

Table 4 about here.

Compared to previous studies, our values are rather conservative. Juks (2018) assumes a conversion rate of 10% for Swedish banks, while Jun and Yeo (2021) expects a CBDC to become the primary means of payment. In Burlon et al. (2022), the authors calculate a utilization rate of 34% of European GDP at the maximum conversion sum of €3,000 and realistically assume values between 15% and 30%. In contrast, Adalid et al. (2022) assume conversion rates between 0.5% and 18% within Europe in their work. We work with our conservative values because, first, we suspect that household use of the CBDC will initially be restrained, and second, our results can be easily scaled because the effects shown become correspondingly stronger for higher usage rates.

4 Method and results

As outlined in Chapter 2, the introduction of a CBDC leads not only to a balance sheet contraction at the bank level but also to shifts between individual balance sheet items. These shifts can cause changes in the liquidity situation and the profitability of banks. In the following, we first describe our method to measure the effects of a CBDC introduction for German savings and cooperative banks and then go into our results.

4.1 Method

Our approach is based on the balance sheet changes described at the end of Chapter 2 and corresponds to the approach of Juks (2018), Adalid et al. (2022), and Bindseil (2020). In contrast to the work mentioned above, we analyze the effects of a CBDC introduction for banks based on individual balance sheet ratios. We show the effects in a precise and understandable way because banks work with these ratios regularly.

In order to model the balance sheet changes due to a CBDC introduction by the central bank shown in Chapter 2, we proceed as follows:

First, we reduce the current customer deposits of banks equal to the percentages calculated in Chapter 3, as customers will convert a part of their demand deposits held in current accounts (€500, €1,000 or €1,500) into CBDC.

Second, for each bank, we calculate the minimum reserves held at the central bank according to the current reserve ratio of 1% of the total customer deposits minus the lump sum of €100,000 (Deutsche Bundesbank, 2022b). Then, subtracting this amount from the cash and reserves at the central bank, we obtain the bank's excess reserves available to purchase CBDC.

In the third step, we reduce banks' cash and central bank reserves by the minimum of either excess reserves or converted deposits, as banks can not dissolve their minimum reserves. We assume that banks must acquire CBDC for their customers from the central bank, and therefore it is evident that stored reserves are used first. If the outflow of customer deposits exceeds the bank's excess reserves, we increase loans taken from other banks or the central bank by the amount exceeding the reserves. In this case, we presume banks finance the outflow of deposits by borrowing on the interbank market or directly from the central bank.

In the final step, we adjust the unencumbered securities. Banks that have to refinance themselves with loans in the previous step must deposit securities in the same amount for the loans taken out. These securities are no longer available to secure liquidity. It must be emphasized that despite the pledging of securities, the amount on the balance sheet does not decrease (see also Juks, 2018).

The changes described earlier also affect a bank's interest income and expenses. First, interest payments on demand deposits converted into CBDC will cease for all banks. In many cases, these bear interest at 0%, but from 2018 until 2020, on average, an effective interest rate of 0.01% was paid on households' overnight deposits in Germany (Deutsche Bundesbank, 2022a), which is now dropped for banks as a result of the conversion. We assume that reserves held at the central bank are non-interest bearing, so banks have no change in interest income when dissolving their excess reserves. However, interest expenses increase for banks that need to refinance at the interbank market or the central bank. For these loans, we assume an interest rate in line with the ECB's current marginal lending rate of 0.75% (European Central Bank, 2022). We do so because we want to examine the implications for a normal interest rate level, where customer deposits are less expensive than interbank loans. However, our calculations can be applied to other interest rate constellations.

In the following two sections, we explain the ratios used to examine the impact of a CBDC implementation.

Liquidity ratios

The global financial crisis of 2007–2009 highlighted the importance of liquidity for the stability of the banking market (Khan et al., 2017; Kladakis et al., 2022). Since then, regulators have successively increased liquidity requirements for banks, for example, with the Basel III regulations and their European implementation (BIS, 2011). As pointed out in Chapter 2, a CBDC introduction reduces central bank reserves and, in the case of some banks, additionally securities, and thus has an impact on banks' liquidity situation.

We use the ratio of liquid assets to total assets as the most important indicator of banks' liquidity situation, as this ratio represents the general capacity of banks to absorb liquidity shocks (Kim and Sohn, 2017; Meriläinen and Junttila, 2020; Kladakis et al., 2022):

$$L_1 := \frac{\text{Liquid Assets}}{\text{Total Assets}}.$$

The higher L_1 is, the more liquidity the bank has available to compensate for fluctuations, making the bank more stable. We use the definitions of Shim (2013) and Kim and Sohn

(2017) for liquidity and determine liquid assets as the sum of cash, central bank reserves, loans to other banks, and securities.

As an extension of L_1, we use the ratio of liquid assets to customer deposits and bank loans, that is, short-term liabilities (Vodová, 2011)

$$L_2 := \frac{\text{Liquid Assets}}{\text{Customer Deposits + Bank Loans}}.$$

L_2 thus shows the ratio of short-term assets to short-term funding sources and is an indicator of a bank's vulnerability to short-term changes in funding sources.

Especially in the case of German savings and cooperative banks, customer loans are among the most illiquid asset positions, as these were usually long-term loans (Deutsche Bundesbank, 2019). Therefore, we measure the share of illiquid loans of the total portfolio with L_3

$$L_3 := \frac{\text{Net Loans}}{\text{Total Assets}}$$

and look at the funding side with L_4 analogous to L_2

$$L_4 := \frac{\text{Net Loans}}{\text{Customer Deposits + Bank Loans}}.$$

The larger these ratios, the higher the share of illiquid loans, and the more difficult it can be for banks to offset liquidity bottlenecks.

Profit Ratios

As Allen et al. (2015) show in their paper, customer deposits play a crucial role in a bank's funding. When customers convert their deposits to CBDC, the bank loses these reliable, low-interest deposits for its funding (Drechsler et al., 2017). As described before, banks without sufficient balances at the central bank must finance the conversion by borrowing from the central bank or interbank loans. Because these usually bear higher interest rates than the lost customer deposits, in addition to the liquidity situation, the profit structure of banks will deteriorate(Jun and Yeo, 2021; Hemingway, 2022). We will assess the profitability situation of banks before and after a CBDC implementation mainly based on the following three ratios.

As general indicators, we use both the return on average assets (ROAA) (García-Herrero et al., 2009; Heggestad, 1977; Bourke, 1989) and the return on average equity (ROAE) (García-Herrero et al., 2009; Goddard et al., 2004; Berger, 1995). Both are established indicators of a bank's profit situation and are widely used in the literature

$$\text{ROAA} := \frac{\text{Net Profit after Taxes}}{\text{Average Total Assets}} \text{ and } \text{ROAE} := \frac{\text{Net Profit after Taxes}}{\text{Average Equity Capital}}.$$

ROAA indicates how many euros of profit are generated per euro of total assets and is thus a measure of the bank's overall efficiency. In contrast, ROAE describes the profit per euro of equity and thus the remuneration of the capital employed.

The primary profit business for small commercial banks is the interest business resulting from the interest margin between deposits taken and loans issued. We analyze the changes resulting from the introduction of the CBDC on the basis of the net interest margin (NIM) (Angbazo, 1997; Maudos and De Guevara, 2004). We follow the definition of Nguyen (2012) and calculate the NIM as the difference between banks' interest income and interest expense as a percentage of average interest-earning assets:

$$\text{NIM} := \frac{\text{Net Interest Income}}{\text{Earning Assets}} = \frac{\text{Interest Income}}{\text{Earning Assets}} - \frac{\text{Interest Expenses}}{\text{Earning Assets}}.$$

4.2 Results

We first consider the implications of a CBDC introduction for a bank's liquidity situation and show the results in Table 5.

Table 5 about here.

As expected, we find the general liquidity situation for all banks and for our subsamples deteriorates due to the CBDC introduction, as banks must dissolve parts of their excess central bank balance to compensate for the outflow of customer deposits. Without a CBDC, on average, banks had a liquidity ratio of $L_1 = 35.12\%$ of total assets, which drops as low as 31.56% when each customer converts €1,500 into the CBDC. Against the background of the current excellent liquidity situation of the banks, this drop of 3.56 pps may not seem much. However, it has the consequence that the average bank loses

51 million euros, or almost 60%, of their excess central bank reserves (see Table 7). In addition, 21 million euros of unencumbered securities are now pledged (see Table 8).

Table 7 about here.

Table 8 about here.

Looking at the number of observations for the subsamples of banks without sufficient excess reserves in our three conversion amount scenarios (the last three columns of Table 5), we see that at a conversion amount of €1,500, more than two-thirds of banks do not have sufficient excess reserves at the Bundesbank (i.e., balances above the minimum reserve of 1%) to offset the conversion of customer deposits to the CBDC. Even with a conversion of €500, or 2.96% (see Table 4), this problem still affects one-third, or 410 banks, of our sample, meaning that these banks must refinance themselves with loans on the interbank market or from the central bank directly. Collateral must be deposited for these loans, further exacerbating the liquidity situation. The high proportion of banks affected in this way is somewhat shocking, as savings and cooperative banks usually do not operate wholesale funding and therefore cannot simply offset the deposit outflow, like Whited et al. (2022) or Juks (2018) suggest. It can also be assumed that the rising demand on the interbank market will cause market interest rates for interbank loans to increase, making future refinancing even more expensive.

If we split the data set between savings and cooperative banks, we only observe a slight difference in the decrease of L_1 between the two banking groups, as savings banks show a decrease of 3.17 pps and cooperative banks one of 3.73 pps, indicating that the overall liquidity situation for both banking groups is similar. However, looking at columns two and three of Table 7, we notice that cooperative banks have much less excess central bank reserves, indicating earlier and higher borrowing and interest payments to refinance a CBDC introduction.

The largest 10% of banks in the sample show a lower liquidity ratio than banks with the smallest 10% of balance sheet totals before the introduction of the CBDC. However, because larger banks have greater excess reserves, they can more often compensate the CBDC conversion in full via these reserves, while smaller banks must look for additional

funds. Thus, the liquidity decline for large banks of 7.22% exceeds that of small banks, which have a L_1 decline of 5.95%, as smaller institutions experience a lower asset-liability reduction as a result of borrowing on the capital market.

As expected, the change of L_2 matches the change of L_1 but is slightly larger in absolute value because the denominator of L_2 is smaller, as only customer deposits and bank loans are included in the calculation of L_2.

Change in the banks' credit exposure adjusts only slowly due to longer-term contracts and maturity transformation. Therefore, we assume that the credit exposure of banks will not decrease immediately despite the reduction of customer deposits. This assumption leads to increasing values for L_3 and L_4, indicating higher proportions of illiquid loans. However, as Kim and Kwon (2022) have shown in their paper, banks might compensate for the loss of customer deposits with credit rationing.

In addition to the changed liquidity situation, we also look at the changes in banks' profitability (see Table 6).

Table 6 about here.

To some surprise and in contrast to the liquidity ratios, we observe for the ROAA only a slight decrease across the different scenarios for the entire sample. If we look at the results for savings and cooperative banks separately, we see that two opposing effects occur here. The ROAA for savings banks rises slightly by 0.5 pps, while cooperative banks lose 1.5 pps. An explanation is the mentioned differences in cash and excess reserves at the central bank between savings and cooperative banks (see Table 7). Banks with enough excess reserves can compensate for the conversion of customer deposits into a CBDC without taking up new loans on the interbank market or the central bank. At this very moment—apart from potentially restrictive lending volumes and a more vulnerable funding structure in the future—these banks benefit from introducing a CBDC by vanishing interest payments on converted customer deposits. These deposit rates have been very low recently but, nevertheless, lead to a slight increase in the ROAA. When jumping from a conversion amount of €1,000 to €1,500, the ROAA for savings banks also decreases from 12.21% to 12.19%, indicating that a point has been reached where savings banks also have insufficient

excessive central bank reserves, meaning that the ROAA is likely to decrease further for higher conversion rates.

The results for the largest and smallest banks are comparable to the findings for savings and cooperative banks. The ROAA for the largest banks initially increases for the scenario of a conversion amount of €500 and €1,000. However, it falls back to the level before a CBDC introduction for a conversion amount of €1,500. This result indicates again that for €1,500, a threshold has been reached at which even large banks will have to start borrowing to refinance the CBDC conversion. In contrast, for the smallest banks, the ROAA decreases for all conversion ratios. As shown in Table 7, these banks indeed have low, excessive reserves and thus start taking loans on the interbank market even for small deductions from current deposits.

Banks without sufficient excess reserves (columns 6–8 of Table 6) are affected earlier than other banks and must already borrow for small conversion amounts, so they are particularly affected.

The impact of changes in the relative ROAA considered so far is distorted by the fact that, in addition to the profit, the total assets are also reduced by the CBDC conversion. Thus a higher ROAA does not necessarily mean that the bank is making more profit. Therefore, we have listed in Table 9 the absolute and relative net income declines due to the CBDC introduction. In fact, the largest banks, for example, are already making losses even for smaller CBDC conversion amounts, even though the ROAA in these cases has increased slightly. These losses rise to over half a million euros per bank on average for a conversion amount of €1,500. Only savings banks make a profit when a CBDC is introduced as long as customers do not convert more than €500. Once again, small banks with little excess reserves are particularly affected. The level of up to 17% of total net income is surprising as the ROAA only decreases by a few percentage points. Nevertheless, the possibility of losing over a tenth of net income is worrying and, for many banks, existence-threatening.

Table 9 about here.

These declines in profits of banks studied are limited only to the decline in customer deposits and the associated funding costs. We thus ignore revenue declines from reduced lending or cost increases from keeping customers' CBDC accounts. The profit losses shown in Table 9 can thus be understood as a lower bound on the costs incurred by banks as a result of the CBDC introduction. The central bank must reimburse the banks for these costs or compensate them in some other way to maintain the status quo.

The findings for the ROAE in Table 6 confirm what we have stated so far: only the numerator of the ROAE changes due to the introduction of CDBC, as we have assumed that the credit portfolio of the bank does not change. Thus, only the savings banks, which are well endowed with central bank reserves (see Table 7), have a slight increase in ROAE for the scenario of a conversion amount of €500, while the ROAE decreases for all other subgroups and all conversion amounts.

We obtain comparable results for the net interest margin in Table 6. Banks with high reserves at the central bank initially have no increased interest expenses for refinancing. In contrast, banks without sufficient reserves have lower margins due to the new interbank or central bank loans. The income interest margin remains constant because we assume that banks do not need to adjust their lending volume. In practice, however, banks will have to ration loans more, as they will lose some of the counterpart funding of loans and must either accept this or compensate it with more expensive interbank loans (Kim and Kwon, 2022).

5 Conclusion

With increasing speed, central banks are considering public access to digital central bank money, and further research about the potential consequences of such a transition becomes essential. The benefits of more efficient and secure payments with state-legitimized digital means of payment face uncertain consequences on the banking sector, monetary policy, and financial stability. We apply mechanisms proposed in the literature to model shifts in aggregated banking sectors and transfer them to the balance sheet data of individual banks. We assume a CBDC whose framework is aligned with trends expected for the digital euro

project and use manually compiled customer and account information to create realistic conversion rates of deposits into a CBDC.

We contribute to the ongoing discussion on the impact of a CBDC on banking systems, particularly the threat of disintermediation due to large withdrawals of customer deposits. For this purpose, we concentrate on banks heavily dependent on customer deposits due to their core business of regional restricted borrowing and lending activities, as these will feel the strongest effects and have the fewest response options. Our results show that especially small institutes in our data set do not have sufficient (excess) reserves at the central bank to substitute demanded CBCD for their customers in the first place. These banks rely on refinancing via the interbank market or expanded central bank funding. We find a surprisingly high number of banks without sufficient reserves within our comparatively conservative take-up scenarios, and these banks face losses of net income ranging from 4.00% to 17.18% compared to previous years. Potential losses due to lower lending volumes in the future would be added to this amount. This extends previous concerns about the uneven distribution of central bank reserves across different types of banks to consequences of uneven distribution within each category. If the central bank does not want to change the status quo of banks by introducing a CBDC, our results for profit losses can be used as a lower bound for compensation and equalization payments.

Our results are essential for the dialogue between commercial banks and policy makers. Commercial banks must consider CBDC induced outflow scenarios based on their customer behavior and prepare for the consequences of an expected persistent loss of deposit. Small credit institutions, essential for a broad range of retail customers and small and medium-sized enterprises, should not be unfairly affected negatively in a one-size-fits-all implementation.

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Table 1: Summary statistics of all banks

Balance sheet position in €	Mean	Sd	p1	p25	p50	p75	p99
Assets side							
Cash & central bank deposits	100,589,443	233,856,215	522,010	6,049,683	26,950,000	109,458,333	870,953,333
Loans to banks	111,254,564	281,043,938	2,585,000	18,200,000	46,066,667	105,300,000	1,143,542,667
Total securities	412,833,215	597,074,747	4,067,770	70,925,000	232,683,333	486,816,667	3,114,019,000
Net loans	1,192,378,855	2,011,387,998	24,435,000	194,688,725	567,666,667	1,341,291,667	8,559,212,667
Total assets	1,867,921,595	2,951,226,381	49,000,333	335,175,000	985,600,000	2,158,475,000	12,757,115,333
Liabilities side							
Current customer deposits	976,204,766	1,623,140,780	18,317,333	154,025,000	472,066,167	1,098,916,667	7,712,355,000
Total customer deposits	1,438,257,185	2,285,122,789	38,836,617	251,385,408	736,033,333	1,685,883,333	10,626,070,667
Interbank loans	212,267,432	340,117,508	2,137,890	33,300,000	107,000,000	247,850,000	1,480,120,000
Total equity	176,275,280	255,345,705	5,085,000	32,908,333	96,966,667	207,791,667	1,204,164,000
Income statements							
Total interest expenses	6,454,010	16,460,206	33,333	666,667	2,166,667	6,100,000	68,023,333
Net interest income	29,568,396	42,616,887	1,000,000	5,866,667	16,516,667	34,333,333	195,693,333
Net income	2,798,625	4,465,196	82,949	466,667	1,300,900	3,100,000	23,196,667

This table reports the summary statistics for all balance sheet variables used in our analysis. Values are calculated based on the average of 2018, 2019 and 2020 for each bank. Sd stands for the standard deviation, and p1, p25, p50, p75 and p99 stand for the first, twenty-fifth, fiftieth, seventy-fifth and ninety-ninth quantiles.

Table 2: Summary statistics of savings banks only

Balance sheet position in €	Mean	Sd	p1	p25	p50	p75	p99
Assets side							
Cash & central bank balance	237,350,605	363,453,892	13,291,667	75,200,000	135,366,667	271,658,333	1,427,541,667
Loans to banks	166,316,901	361,995,463	5,141,667	36,275,000	83,066,667	180,158,333	1,295,816,667
Total securities	729,907,161	769,072,613	34,875,000	286,241,667	485,016,667	908,716,667	3,583,708,333
Net loans	2,248,812,541	2,923,797,282	161,641,667	760,750,000	1,338,883,333	2,628,900,000	12,892,808,333
Total assets	3,457,174,868	4,180,830,122	260,725,000	1,382,966,667	2,219,666,667	4,010,383,333	20,073,483,333
Liabilities side							
Current customer deposits	1,812,388,501	2,209,855,964	126,133,333	622,991,667	1,136,850,000	2,153,550,000	12,912,591,667
Total customer deposits	2,655,229,967	3,171,315,266	210,100,000	1,029,708,333	1,746,566,667	3,233,458,333	16,737,266,667
Interbank loans	379,092,293	490,996,650	15,575,000	121,150,000	223,150,000	441,750,000	1,945,500,000
Total equity	331,270,715	353,705,257	27,383,333	126,865,250	211,216,667	400,275,000	1,660,991,667
Income statements							
Total interest expenses	13,547,467	25,382,810	725,000	3,625,000	6,916,667	13,325,000	102,083,333
Net interest income	54,261,485	59,407,944	4,266,667	20,791,667	35,316,667	65,066,667	245,666,667
Net income	4,444,685	6,321,492	75,000	900,000	2,100,000	5,200,000	31,841,667

This table reports the summary statistics for all balance sheet variables used in our analysis. Values are calculated based on the average of 2018, 2019 and 2020 for each savings bank. Sd stands for the standard deviation, and p1, p25, p50, p75 and p99 stand for the first, twenty-fifth, fiftieth, seventy-fifth and ninety-ninth quantiles.

Table 3: Summary statistics of cooperative banks only

Balance sheet position in €	Mean	Sd	p1	p25	p50	p75	p99
Assets side							
Cash & central bank balance	35,988,694	72,241,784	365,853	3,333,333	10,616,667	34,691,667	353,003,333
Loans to banks	85,245,219	228,953,094	2,363,333	14,822,433	34,366,667	77,500,000	1,113,843,333
Total securities	262,303,160	418,418,473	3,133,581	49,575,000	126,600,000	318,125,000	2,428,383,667
Net loans	693,359,928	1,072,184,837	22,136,667	130,066,667	316,683,333	841,616,667	5,339,486,667
Total assets	1,117,219,044	1,680,853,074	44,882,410	221,433,333	535,980,017	1,343,733,333	7,994,035,000
Liabilities side							
Current customer deposits	581,223,505	1,044,131,183	17,225,343	101,929,708	251,800,000	645,700,000	5,047,363,333
Total customer deposits	863,405,720	1,384,251,176	35,523,333	168,450,000	392,276,733	1,006,625,000	6,450,956,667
Interbank loans	133,366,618	192,844,083	1,829,793	22,016,667	62,933,333	163,033,333	872,378,000
Total equity	103,061,356	142,466,793	4,226,492	22,716,667	52,550,000	131,066,667	688,030,000
Income statements							
Total interest expenses	3,103,332	7,754,507	33,333	422,192	1,100,000	3,075,000	38,791,667
Net interest income	17,904,323	24,203,497	832,948	4,066,667	9,250,000	22,500,000	126,483,333
Net income	2,021,089	2,937,908	88,453	366,667	966,667	2,433,333	13,486,667

This table reports the summary statistics for all balance sheet variables used in our analysis. Values are calculated based on the average of 2018, 2019 and 2020 for each cooperative bank. Sd stands for the standard deviation, and p1, p25, p50, p75 and p99 stand for the first, twenty-fifth, fiftieth, seventy-fifth and ninety-ninth quantiles.

Table 4: Usage rates of a digital euro

Conversion amount per customer	n	Mean in %	Sd in %	p25 in %	p50 in %	p75 in %
€500	270	2.96	3.00	2.08	2.52	3.07
€1,000	270	5.92	6.00	4.17	5.04	6.14
€1,500	270	8.88	8.99	6.25	7.56	9.22

This table reports the descriptive statistics for the conversion rates in the percentage of the current customer deposits for a conversion of €500, €1,000 and €1,500 per customer for the $n = 270$ banks of our data set that report their number of customers. Sd stands for the standard deviation; p25, p50, and p75 represent the twenty-fifth, fiftieth, and seventy-fifth quantiles.

Table 5: Liquidity ratios

		All banks	Savings banks	Cooperative banks	Top 10%	Bottom 10%	No reserves at €500	No reserves at €1,000	No reserves at €1,500
	Observations	1,172	376	796	118	118	410	578	824
L_1	no CBDC	0.3512	0.3508	0.3513	0.3281	0.3562	0.3800	0.3656	0.3581
	€500 conversion	0.3405	0.3409	0.3403	0.3165	0.3456	0.3677	0.3540	0.3469
	€1,000 conversion	0.3285	0.3305	0.3276	0.3040	0.3333	0.3533	0.3402	0.3341
	€1,500 conversion	0.3156	0.3191	0.3140	0.2903	0.3205	0.3390	0.3258	0.3201
L_2	no CBDC	0.3961	0.3980	0.3952	0.3711	0.4014	0.4273	0.4115	0.4036
	€500 conversion	0.3846	0.3876	0.3832	0.3586	0.3899	0.4137	0.3989	0.3915
	€1,000 conversion	0.3715	0.3765	0.3692	0.3451	0.3762	0.3975	0.3834	0.3774
	€1,500 conversion	0.3572	0.3641	0.3540	0.3300	0.3618	0.3814	0.3672	0.3616
L_3	no CBDC	0.6147	0.6281	0.6083	0.6468	0.5989	0.5824	0.5965	0.6042
	€500 conversion	0.6217	0.6376	0.6142	0.6570	0.6038	0.5853	0.6012	0.6103
	€1,000 conversion	0.6273	0.6473	0.6179	0.6667	0.6061	0.5853	0.6025	0.6142
	€1,500 conversion	0.6313	0.6558	0.6197	0.6744	0.6071	0.5853	0.6025	0.6157
L_4	no CBDC	0.6944	0.7135	0.6853	0.7349	0.6774	0.6565	0.6728	0.6820
	€500 conversion	0.7034	0.7258	0.6928	0.7481	0.6837	0.6603	0.6789	0.6899
	€1,000 conversion	0.7106	0.7383	0.6975	0.7608	0.6866	0.6603	0.6806	0.6949
	€1,500 conversion	0.7157	0.7494	0.6998	0.7710	0.6879	0.6603	0.6806	0.6969

This table reports the results for our liquidity ratios, L_1, L_2, L_3 and L_4, in the case of no CBDC and for a conversion amount of €500, €1,000 and €1,500. In the sample of the Top 10%, we include all banks that are in the top 10% of total assets, while in the sample of Bottom 10%, we include all banks that are in the bottom 10% of total assets. The last three columns correspond to banks that do not have enough excess central bank reserves at a conversion amount of €500, €1,000 or €1,500.

Table 6: Profitability ratios

		All banks	Savings banks	Cooperative banks	Top 10%	Bottom 10%	No reserves at €500	No reserves at €1,000	No reserves at €1,500
Observations		1,172	376	796	118	118	410	578	824
ROAA	no CBDC	0.1794	0.1184	0.2082	0.1536	0.2419	0.2019	0.2054	0.1941
	€500 conversion	0.1790	0.1204	0.2067	0.1554	0.2399	0.1959	0.2021	0.1926
	€1,000 conversion	0.1758	0.1221	0.2012	0.1560	0.2332	0.1849	0.1931	0.1871
	€1,500 conversion	0.1701	0.1219	0.1929	0.1536	0.2246	0.1739	0.1821	0.1780
ROAE	no CBDC	1.7584	1.1727	2.0354	1.6081	2.3333	1.9550	1.9882	1.8922
	€500 conversion	1.7351	1.1741	2.0004	1.5994	2.2947	1.8853	1.9393	1.8584
	€1,000 conversion	1.6899	1.1718	1.9349	1.5780	2.2219	1.7761	1.8458	1.7934
	€1,500 conversion	1.6243	1.1541	1.8467	1.5297	2.1339	1.6669	1.7368	1.6994
NIM	no CBDC	1.8565	1.7736	1.8957	1.6948	2.0464	1.8570	1.8839	1.8645
	€500 conversion	1.8541	1.7738	1.8921	1.6941	2.0423	1.8498	1.8789	1.8610
	€1,000 conversion	1.8494	1.7736	1.8852	1.6924	2.0346	1.8385	1.8691	1.8542
	€1,500 conversion	1.8425	1.7717	1.8760	1.6881	2.0253	1.8272	1.8578	1.8444
NIM-income	no CBDC	2.1517	2.1605	2.1475	2.1099	2.2678	2.0942	2.1323	2.1279
	€500 conversion	2.1517	2.1605	2.1475	2.1099	2.2678	2.0942	2.1323	2.1279
	€1,000 conversion	2.1517	2.1605	2.1475	2.1099	2.2678	2.0942	2.1323	2.1279
	€1,500 conversion	2.1517	2.1605	2.1475	2.1099	2.2678	2.0942	2.1323	2.1279
NIM-expenses	no CBDC	0.2954	0.3869	0.2522	0.4152	0.2246	0.2377	0.2487	0.2637
	€500 conversion	0.2978	0.3867	0.2558	0.4158	0.2287	0.2450	0.2538	0.2672
	€1,000 conversion	0.3025	0.3869	0.2626	0.4175	0.2364	0.2563	0.2635	0.2740
	€1,500 conversion	0.3094	0.3888	0.2718	0.4218	0.2458	0.2676	0.2749	0.2838

This table reports the results for our profitability ratios, return on average assets (ROAA), return on average equity (ROAE) and the net interest margin (NIM), in the case of no CBDC and for a conversion amount of €500, €1,000 and €1,500. In the sample of the Top 10%, we include all banks that are in the top 10% of total assets, while in the sample of Bottom 10%, we include all banks that are in the bottom 10% of total assets. The last three columns correspond to banks that do not have enough excess central bank reserves at a conversion amount of €500, €1,000 or €1,500.

Table 7: The change of central bank deposits

	All banks	Savings banks	Cooperative banks	Top 10%	Bottom 10%	No reserves at €500	No reserves at €1,000	No reserves at €1,500
Observations	1,172	376	796	118	118	410	578	824
Cash & central bank deposits	100,589,443	237,350,605	35,988,694	515,298,588	2,012,675	11,739,720	20,790,839	49,705,614
Excessive cash & central bank deposits	86,306,872	210,898,305	27,454,636	450,952,319	1,355,771	4,922,017	13,007,121	38,616,081
Cash & central bank deposits for €500 conversion	74,832,790	183,920,011	23,304,153	389,489,884	1,239,723	6,817,703	11,181,345	31,288,144
Cash & central bank deposits for €1,000 conversion	52,139,668	132,546,043	14,158,768	274,774,915	887,630	6,817,703	7,783,718	17,228,028
Cash & central bank deposits for €1,500 conversion	35,016,014	87,610,578	10,172,350	184,059,337	731,993	6,817,703	7,783,718	11,089,533

This table reports the mean values of the total cash and central bank deposits for our samples as well as the excess cash and central bank deposits before a CBDC is introduced. It further shows the mean values of the total cash and central bank deposits for the three conversion amounts of €500, €1,000 and €1,500. In the sample of the Top 10%, we include all banks that are in the top 10% of total assets, while in the sample of Bottom 10%, we include all banks that are in the bottom 10% of total assets. The last three columns correspond to banks that do not have enough excess central bank reserves at a conversion amount of €500, €1,000 or €1,500.

Table 8: The change of bank loans

	All banks	Savings banks	Cooperative banks	Top 10%	Bottom 10%	No reserves at €500	No reserves at €1,000	No reserves at €1,500
Observations	1,172	376	796	118	118	410	578	824
Loans from banks with no CBDC	212,267,432	379,092,293	133,366,618	829,610,734	11,620,098	91,466,267	118,936,001	164,117,845
Loans from banks for €500 conversion	215,408,967	379,308,399	137,891,751	839,282,878	12,165,768	100,460,734	125,311,628	168,587,756
Loans from banks for €1,000 conversion	221,616,603	381,581,130	145,960,425	860,048,756	13,135,431	114,389,120	137,909,795	177,420,250
Loans from banks for €1,500 conversion	233,398,463	390,292,365	159,194,554	904,814,026	14,303,230	128,317,506	153,911,477	194,183,989

This table reports the mean values of loans taken from other banks and the central bank before a CBDC was introduced and for the three conversion amounts of €500, €1,000 and €1,500. In the sample of the Top 10%, we include all banks that are in the top 10% of total assets, while in the sample of Bottom 10%, we include all banks that are in the bottom 10% of total assets. The last three columns correspond to banks that do not have enough excess central bank reserves at a conversion amount of €500, €1,000 or €1,500.

Table 9: The loss of net income

	All banks	Savings banks	Cooperative banks	Top 10%	Bottom 10%	No reserves at €500	No reserves at €1,000	No reserves at €1,500
Observations	1,172	376	796	118	118	410	578	824
Loss of net income (absolute) for €500 conversion	19,291	−4,042	30,327	52,227	3,790	62,502	43,657	29,374
Loss of net income (absolute) for €1,000 conversion	62,796	7,341	89,024	193,670	10,922	165,495	136,454	93,199
Loss of net income (absolute) for €1,500 conversion	148,107	67,012	186,461	515,109	19,541	268,488	254,778	216,509
Loss of net income (in %) for €500 conversion	0.6890	−0.0909	1.5000	0.4378	1.6412	4.0004	2.3995	1.2306
Loss of net income (in %) for €1,000 conversion	2.2429	0.1652	4.4032	1.6236	4.7303	10.5923	7.4998	3.9044
Loss of net income (in %) for €1,500 conversion	5.2900	1.5077	9.2225	4.3184	8.4629	17.1843	14.0031	9.0702

This table reports the mean values for the loss of banks' net income for €500, €1,000 and €1,500 CBDC conversion in absolute values and relative to banks' net income without a CBDC. In the sample of the Top 10%, we include all banks that are in the top 10% of total assets, while in the sample of Bottom 10%, we include all banks that are in the bottom 10% of total assets. The last three columns correspond to banks that do not have enough excess central bank reserves at a conversion amount of €500, €1,000 or €1,500.