# Digital Currencies in Financial Networks

**Abstract**

We introduce a digital currency, either as a central bank digital currency (CBDC) or a crypto financial asset (stablecoin), in the network of financial accounts. Simulating a shift of deposits by both households and non-financial corporations from the banking sector to the digital currency, we model the different responses of the affected institutional sectors. We find that the introduction of a digital currency generates significant adjustments in the balance sheets of all sectors, may trigger large moves in securities prices, generate funding shortages, and induce changes in the financial network structure. The economic impacts vary depending on the design of the digital innovation, the size of the deposit shift, the channels through which the balance sheet adjustments take place, and the timing of the initiative.
*JEL classification:* G21, E58

*Keywords:* Digital currency; CBDC; Stablecoins; Macro-network; Financial Intermediation; Financial Stability

## 1. Introduction

Digital currencies have the potential to shape the future of banking and financial intermediation. Whether the provision of a digital currency is by the public sector (central bank digital currency, CBDC) or a by a private initiative (referred to in this paper as a stablecoin), the eventual rollout of such new instruments is likely to provide a significant boost to the retail use of digital assets. At the same time, financial innovations may create new risks and vulnerabilities whose implications should always be thoroughly assessed. This paper analyses the introduction of digital currencies in the network of financial accounts. We identify key channels through which the effects of these novel instruments materialize in the network, and we reveal significant direct and indirect consequences for most parts of the financial system.

Among the potential risks of a disorderly transition is the possibility that, depending on the ultimate role of existing financial intermediaries, the commercial banking system may experience the intractable loss of its fee-generating payment business, erosion of retail deposit funding and disintermediation of its core lending functions, with adverse consequences for the efficient allocation of credit to the economy.

The starting point of our paper is the introduction of a digital currency in the financial accounts. We consider a CBDC as a deposit scheme similar to the existing central bank deposit facilities, but with an extended list of counterparties, including non-financial agents. We classify stablecoins as a new deposit instrument, termed "non-MFI deposits". Armed with these definitions, we build on the work in Castrén and Kavonius (2013) and Castrén and Rancan (2014) and incorporate the new financial assets into the "Macro-Network", a network of bilateral exposures among the institutional sectors of the economy. We model the introduction of a digital currency as a deposit shift out of commercial banks to the digital currency. Then, under the different designs, we introduce a set of reactions of the banking sector and investigate the implications that its adjustment may have on the other sectors. We find that in the process of balance sheet adjustments, the heterogeneous portfolios of bonds and loans held by the different sectors imply that the set of tradable assets that one sector may have to sell is not the same as the set of assets that another sector may be willing to buy. Price adjustments are then required to allow the markets to clear.

Shock simulations give rise to the following main findings. First, we identify the key channels through which the introduction of digital currencies propagates to the main sectors of the economy. We show that even a relatively limited loss of deposits is sufficient to generate significant funding gap that triggers major adjustments in banking-sector balance sheets. This, in turn, has implications for other sectors. When the banking sector redeems loans, households experience the largest impact. In the case in which the banking sector reacts, instead, by selling securities, non-financial corporations are most affected. The option for banks to issue new debt securities may require a significant drop in prices, increasing their funding costs. Second, by invoking network centrality measures, we observe changes in the relative importance of the individual nodes of the network (the institutional sectors). The introduction of a CBDC or stablecoin will cause the sector issuing the digital currency to become a more central player in the network at the expense of the banking sector, but the process also has important consequences for third parties, such as the "rest of the world" sector. By changing the shape of the macro network, the introduction of a digital currency may also affect the network's stability properties. Our findings therefore also support the view that the regulation of digital currencies should take into account wider effects than just the immediate counterparty exposures. Finally, we show that because the key properties of financial networks are time-varying, it is not only the design of a digital currency but also the timing of its launch that matter in terms of the impact on the financial system.

Our paper contributes to a rapidly growing body of academic literature devoted to the study of the design and implications of digital currencies. Theoretical models include among others Andolfatto (2018), Kim and Kwon (2019), Agur et al. (2019), Keister et al. (2019), Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al. (2020). These authors investigate the effects of different digital currency designs on bank lending, and banks' deposit market power, cost of funding and aggregate welfare, with sometimes conflicting results. While we do not derive a general equilibrium model, our paper provides a comprehensive framework to simulate the economic impact of the introduction of a digital currency covering several possible scenarios. On the more conceptual side, Brunnermeier et al. (2019) discuss the effect of these instruments on models of monetary exchange and currency competition. Adrian and Griffoli (2019) propose a conceptual framework to categorize digital monies and Bullmann et al. (2019) provide a taxonomy of the various models of private digital currencies. Using financial balance sheets, Kumhof and Noone (2018) study the introduction of CBDC and derive a set of "core principles" that could prevent runs from retail deposits to CBDC. Bindseil (2020) analyses the system-wide impact of both a CBDC and private digital currencies and argues that a two-tiered remuneration system may be sufficient to mitigate the risk of retail deposit runs to the CBDC. In Kumhof and Noone (2018) and Bindseil (2020), shocks to individual sectors' asset and liability positions are immediately rebalanced by offsetting shifts in homogeneous asset and liability items. These models implicitly assume that there is only one type of financial asset that can be exchanged in the account rebalancing process. With respect to these papers, our framework accounts for the existing heterogeneity in the portfolios of the different sectors and quantifies the impact in the financial system under various design of the digital currency.

The remainder of this paper proceeds as follows. First, Section 2 presents the data and proposes an allocation of the different types of digital currencies into the financial accounts. Then, Section 3 introduces the methodology and the macro-network approach to modelling financial interlinkages. Next, Section 4 includes the simulation exercises to assess the dynamic impact of the introduction of a digital currency. Section 5 then generalises the results by looking at different shock sizes and assesses the time varying impact on network structures. Section 6 concludes.

## 2. Data

We use data on sector-level financial accounts – often referred to as flow of funds – from the Euro Area Accounts (EAA), published jointly by the ECB and Eurostat. In the EAA, the analytical grouping of economic agents into institutional sectors and transactions follows the methodological framework established in the European System of Accounts 2010 (ESA2010, the European application of the 2008 System of National Accounts, SNA2008). Ten distinct institutional sectors are considered: households, including non-profit institutions serving households (HH), nonfinancial corporations (NFC), banks (MFI), the central bank (CB), insurance companies (INS), pension funds (PF), other financial intermediaries (OFI), non-money-market-fund investment funds (INV), general government (GOV), and the rest of the world (ROW). Owing to the inclusion of the rest of the world sector, the asset and liability items also include instruments originating from foreign counterparties. Together, these sectors cover the complete financial accounts of the domestic economy, and, by including the ROW sector, the system is closed, i.e. each financial asset item that is held by a sector has a counterparty item on the liability side of some other sector.[1] The categories of financial instruments that constitute the sector-specific balance sheets are distinguished in the ESA2010 and are classified according to liquidity factors and legal characteristics. The analysis in this paper covers the following instrument types: currency, deposits, debt securities, loans and investment fund shares. The EAA provide who-to-whom tables, i.e. the cross-sector bilateral financial exposures, for all these instruments categories from Q1 2015 to Q1 2019.[2]

Despite of the potential for digital currencies to play an important role in the future of banking and finance, allocating these instruments within the system of financial accounts, or in regulatory or accounting standards, is not a straightforward task. At the time of writing the debate on national accounts' treatment of digital currencies remains inconclusive (see. e.g., IMF, 2018; OECD, 2018), we make the following two working assumptions in order to allocate CBDCs and stablecoins and their issuers within the system of financial accounts:

- *For a CBDC:* Under the institutional sector of a central bank, a CBDC is a deposit instrument similar to existing central bank deposit facilities

[1] Note that in the financial accounts, the ROW sector is not a "residual" sector; rather, it has its own sources and accounts that are calculated independently, as in the case of any other sector, describing both domestic residence units' assets and liabilities abroad or foreign residence units' assets and liabilities in the domestic economy. The EAA data are non-consolidated, which means that they include financial links not only between the sectors but also within the sectors in the system.

[2] Data are available on ECB Statistical Data Warehouse.

but with an extended list of counterparties, including non-financial agents.

- *For stablecoins:* Under the institutional sector of non-money market fund investment funds, stablecoin is a new instrument listed as "non-MFI deposits". In addition, for stablecoins, both domestic and foreign initiatives will be considered. In the case of the latter, the institutional sector hosting the stablecoin will be the "rest of the world" sector, but we assume that there will be a local domestic subsidiary (possibly due to a regulatory requirement) in the domestic investment funds sector.

It is of course entirely possible that stablecoins will be classified as credit institutions or deposit taking institutions, or as electronic money institutions, in which case the relevant instrument category could be deposits, as is the case for commercial banks today.[3]

## 3. Introducing Digital Currency in Macro-Networks

### *3.1. The financial system*

This section sets up the model which we then fit to the EEA data, introduced in Section 2. The financial system consists of $n$ institutional sectors $i$, $i = 1, \ldots, n$, with $n = 10$. The liability side of the balance sheet of

[3] Additionally, if the stablecoin reserve fund were to strictly invest only in deposit-like assets (either commercial bank sight deposits or short-term government securities), the scheme could be classified as a money market fund. However, in all these cases, the institutional sector would be the MFI, and the introduction of a stablecoin would thus involve internal shifts within the MFI sector only. Illustrating such moves in a financial accounts network would require who-to-whom data for the MFI sub-sectors, which are currently unavailable in the Euro Area Accounts.

sector $i$ in time $t$, $L_{i,t}$, encompasses $X$ items including quoted and unquoted equity shares ($EQ$), deposits, credit (loans) and debt securities and loans ($DD$), other items ($OI$)[4] and net wealth ($NW$), where the latter is defined as total assets minus total liabilities. Formally, we have:

$$L_{i,t} = EQ_{i,t}^L + DD_{i,t}^L + OI_{i,t}^L + NW_{i,t}^L$$

where the superscripts $L$ denote liability items and $DD_{i,t}^L = D_{i,t}^L + B_{i,t}^L + C_{i,t}^L$ is a portfolio of debt items deposits ($D^L$), bonds ($B^L$) and credit ($C^L$). Each item $X_{i,t}^L$ can be represented as $\sum_{j=1}^n \omega_{i,j,t}^{X^L} X_{i,t}^L$ with weights $\omega$, that are sector-, items- and time-specific. The asset side of sector $i$ is defined as:

$$A_{i,t} = EQ_{i,t}^A + DD_{i,t}^A + OI_{i,t}^A$$

where superscripts $A$ denote asset items and $EQ_{i,t}^A$, $DD_{i,t}^A$ and $OI_{i,t}^L$ are portfolios of equity, debt and other assets issued by all sectors $j$, including sector $i$ itself. Each asset item $X_{i,t}^A$ can be expressed as $\sum_{i=1}^n \omega_{i,j,t}^{X^A} X_{i,t}^A$. At the financial system level, with the rest of the world sector, we have:

$$\sum_{i=1}^n L_{i,t} = \sum_{i=1}^n A_{i,t} \text{ and } \sum_{i=1}^n NW_{i,t} = 0$$

[4]The largest items in the "Other Items" category are liabilities associated with insurance companies (pre-paid insurance premiums), pension funds (paid pension liabilities) as well as money market and investment fund shares. The counterparty sectors to the first two types of items on the asset side are mainly households and non-financial corporations, and for the latter items households and MFIs.

The latter condition means that even if the net wealth positions may be non-zero at sector level, at the financial system level they cancel out. If the domestic sectors in aggregate show a positive (negative) net wealth position, this will be reflected by an offsetting current account surplus (deficit) position *vis-à-vis* the rest of the world.[5]

*3.2. The Macro-Network*

Following Castrén and Kavonius (2013) and Castrén and Rancan (2014), we model the EAA data, introduced in 2, as a macro-network. The macro-network consists of a set of bilateral links between the main institutional sectors which constitute the nodes of the network. The links of the network are the EAA who-to-whom statistics for the different financial instruments. Formally, $\omega^X_{i,j,t}X_{i,t}$ corresponds to links from sector $i$ to sector $j$ at time $t$, for instrument $X$. Separate macro-networks are drawn for the different financial instruments. The macro-network allows us to model the financial system as an intertwined set of agents that is particularly suitable to account for shock propagation and feedback effects.[6]

Figure 1 shows the status quo macro-networks of two separate instrument

[5]The domestic sectors that typically show negative net wealth positions (i.e. they are net borrowers in the system) are the government and the non-financial corporate sectors. The main surplus, or creditor, sector is the households. The financial sectors are mostly financial intermediaries and tend to have nearly balanced net wealth positions.

[6]There is now an extensive body of literature on financial networks. In their study of bank runs, Allen and Gale (2000) demonstrated the different contagion effects implied by complete versus incomplete network structures. Several papers study contagion effects across financial institutions, using interbank loans as financial links (see, e.g., Upper and Worms, 2004; Gai and Kapadia, 2010; Mistrulli, 2011; Glasserman and Young, 2015). Some authors have considered a broader set of interlinkages between banks, both on the asset and the liability side, with the aim of better characterizing the way in which financial

categories, deposits (Panel A) and debt securities (Panel B). The directions of the links between the nodes (the sectors) show the direction of a claim (from liabilities to assets). In the case of deposits, the households (HH), the non-financial corporates (NFC) and the rest of the world (ROW) sectors hold deposit claims that are issued mostly by commercial banks (monetary financing institutions, MFIs). The network is incomplete and dominated by strong links between a small number of sectors. By contrast, the network of debt securities is much more complete, as the issuance and holdings of these instruments are more evenly distributed across the sectors.[7]

### *3.3. The issuance of a digital currency*

Next, we assume that at time $t+1$, the digital currency is issued, depending on the particular design and institutional classification of the scheme, either by the central bank (CB), the investment funds sector (INV), or the rest of the world sector (ROW). The introduction of the digital currency implies a shock $\varepsilon$ in the form of a switch withdrawal of deposits by both households (HH) and non-financial corporations (NFC) from MFI to the sector $y$ hosting the digital currency, with $y \in \{CB, INV, ROW\}$. For-

institutions are connected to each other (Aldasoro and Alves, 2018; Poledna et al., 2015; Bargigli et al., 2015; Caccioli et al., 2014). Papers that investigate network structures and their properties include Craig and Von Peter (2014) and Peltonen et al. (2014). Departing from the micro-level analysis, some authors treat the network nodes as more aggregate entities, such as countries (see, e.g., Kali and Reyes, 2010) or industries (see, e.g., Acemoglu et al., 2016).

[7]Note that because the data from Euro Area Accounts are non-consolidated, they include intra-sector exposures. For the clarity of the presentation, the intra-sector links are not shown in the graphs, but they are always accounted for in the calculations.

mally:

$$\mathrm{L}_{MFI,t+1} = EQ^L_{MFI,t+1} + (DD^L_{MFI,t+1} - \varepsilon) + OI^L_{MFI,t+1} + NW^L_{MFI,t+1}, \text{ and}$$

$$\mathrm{L}_{y,t+1} = EQ^L_{y,t+1} + (DD^L_{y,t+1} + \varepsilon) + OI^L_{y,t+1} + NW^L_{y,t+1}$$

If we assume that the sectors will not absorb the shock in their net wealth positions, i.e. $NW_{i,t+2} = NW_{i,t+1} = NW_i$, then, at $t+2$ we have, for sector $y$:

$$A_{y,t+1} = EQ^A_{y,t+1} + (DD^A_{y,t+1} + \varepsilon) + OI^A_{y,t+1}$$

We assume that to offset the increase in its deposit liabilities, the sector issuing the digital currency may choose one of the following options:

i) $A_{y,t+2} = EQ^A_{y,t+2} + (DD^A_{y,t+1} + \delta D) + OI^A_{y,t+2}$

ii) $A_{y,t+2} = EQ^A_{y,t+2} + (DD^A_{y,t+1} + \delta B) + OI^A_{y,t+2}$

iii) $A_{y,t+2} = EQ^A_{y,t+2} + (DD^A_{y,t+1} + \delta C) + OI^A_{y,t+2}$

With $\delta D = \delta B = \delta C \equiv \varepsilon$. Option (i) means that sector $y$ redeposit the funds with the commercial banks (MFIs). Under option (ii), sector $y$ purchases debt securities to offset its increase in investible funds. Under option (iii), the sector issuing the digital currency treats the deposits as loanable funds and extends credit (loans). On the other hand, to offset the reduction in its deposit liabilities the MFI sector may, either:

i) $L_{MFI,t+2} = EQ^L_{MFI,t+2} + (DD^L_{MFI,t+1} + \delta D) + OI^L_{MFI,t+2} + NW_{MFI,t+2}$

ii) $A_{MFI,t+2} = EQ^A_{MFI,t+2} + (DD^A_{MFI,t+1} - \delta B) + OI^A_{MFI,t+2}$

iii) $A_{MFI,t+2} = EQ^A_{MFI,t+2} + (DD^A_{MFI,t+1} - \delta C) + OI^A_{MFI,t+2}$

iv) $L_{MFI,t+2} = EQ^L_{MFI,t+2} + (DD^L_{MFI,t+1} + \delta B) + OI^L_{MFI,t+2} + NW_{MFI,t+2}$

Where $\delta D = \delta B = \delta C = \delta B \equiv \varepsilon$. The response by the MFI may be in the form of an increase in the deposit liability portfolio (receiving re-deposited funds from sector $y$, $\delta D$), a reduction in the bond asset portfolio ($\delta B$), a reduction in the bank credit asset portfolio ($\delta C$), or an increase in the bond liability portfolio (new issuance, $\delta B$). Crucially, although the sizes of the various portfolio shifts by MFI are equal to the portfolio shifts by sector $y$, the compositions of the asset portfolios are different.

Following previous literature (see, e.g., Greenwood et al., 2015), we assume that banks sell bonds/redeem loans keeping exposures to different sectors constant.[8] In a similar fashion, sectors that purchase debt securities are assumed to maintain the proportion to their existing holdings.

The assets sold/liabilities issued by MFI and the assets purchased by sector $y$ are not identical, and the transactions may therefore require price adjustments to allow the markets to clear.[9] Moreover, the changes in bilateral exposures at $t + 2$ may trigger further adjustments in the system (e.g.

[8] However, alternative strategies could be considered. For example, banks could sell bonds based on the risk characteristics: the bonds with the lowest ratings and/or the highest risk weights (such as high-yield corporate bonds) would be offloaded first, whereas the bonds with the lowest risk weights (those issued by the government sector, with zero risk weight) would be the last ones to be sold. Another strategy would be to sell the most liquid bonds first (i.e. government bonds and securities issued by high rated corporates), an approach that would typically be deployed in emergency, or fire-sale, situations.

[9] While we do not explicitly model prices, our analysis below provides insights about the sectors whose securities will be most affected in different scenarios. See Greenwood et al.

the sector that looses bank financing under MFI options (ii) and (iii) at time $t + 2$ could replace it by issuing its own debt securities). Several additional rounds of rebalancing could be considered to incorporate more periods into the analysis. Since our focus is on the immediate effects of the introduction of a digital currency, we limit the contagion analysis to only the first stages of the process. Concerning the set of actions, we do not derive a general equilibrium model; in reality, sectors $y$ and MFI are likely to take some combination of the options above.

## 4. Scenario analysis: Digital Currency as a Deposit Scheme

We consider the case where the digital currency is classified as a deposit scheme analyzing in details three separate options for the institutional classification of the digital currency. In option one, the digital currency issuer is the central bank (Section 4.1). In option two, the digital currency issuer is a private entity, operating as part of the investment funds sector (Section 4.1.1). In option three, the issuer is a foreign stablecoin located in the "rest of the world" sector but with part of its global reserve fund assets denominated in the domestic currency (Section 4.1.2). The vehicle controlling the domestic fraction of the reserve fund is a locally licenced and supervised subsidiary within the domestic investment funds (INV) sector. In all scenarios, as baseline we consider the EAA data that refer to Q1 2019 and the initial shock is a withdrawal of 20% of the stock of MFI deposits by both households and firms.

(2015); Adrian and Shin (2010) for papers that investigate financial fragility considering fire sales and leverage targeting.

### 4.1. Central Bank Digital Currency (CBDC)

Consider first the case of a CBDC. Figure 2 illustrates the impact of the introduction of the CBDC at $t = 1$, step-by-step. Panel A depicts the network of deposits before the introduction of the CBDC (the status quo situation). In Panel B, private non-financial-sector depositors have withdrawn 20% of their commercial bank (MFI) deposits (the light blue arrows show the "weakened" deposit links after the withdrawals). In Panel C, the deposits withdrawn from the commercial banks have been placed in accounts with the central bank, so that households and firms now hold direct claims against the central bank (the dark blue arrows).

As explained in general terms in Section 3.3, the shifts in deposits trigger wider changes in the affected sectors' balance sheet aggregates at $t = 2$. We consider a non-exhaustive list of four alternative scenarios – each of which describe a set of actions independently taken by the relevant agents – that are sufficient to complete the process.

i) *Case A.* The CB redeposits the funds with the commercial banks (MFIs) to offset the increase in its deposit liabilities;

ii) *Case B.* The MFI sells debt securities (assets) to offset the reduction in its deposit liabilities; the CB purchases debt securities to offset the increase in its deposit liabilities;

iii) *Case C.* The MFI redeems loans (assets) to offset the reduction in its deposit liabilities; the sector which loses bank financing replaces loans by issuing its own debt securities; the CB purchases debt securities to offset the increase in its deposit liabilities;

iv) *Case D.* The MFI issues debt securities (liabilities) to offset the reduction in its deposit liabilities; the CB purchases debt securities to offset the increase in its deposit liabilities.

As a result of all these transactions, the central bank's balance sheet expands while the commercial banks' balance sheet either shrinks (in cases B and C) or remains unchanged (in cases A and D). This does not necessarily have to be the case, however. The central bank could also decide to offset the increase in its liabilities by using the CBDC as a substitute for other liability items, for example by retiring banknotes. Importantly, while in cases B to D the commercial banks either sell securities from their portfolios or issue securities as new liabilities, and the central bank simultaneously purchases securities, the sales and purchases are made independently and do not necessarily match in terms of their composition. This is because the securities holdings (portfolios) of each sector are different, and therefore the preferred sets of securities to be purchased and sold are not the same. We return to this point shortly.

Figure 3 shows case A. The re-depositing of the funds by the CB to the commercial banks (MFIs) is shown by the blue arrow. In practice, the transaction is a monetary policy operation whereby the banks tap the central bank repo financing facility to cover their funding gaps. Although, in terms of balance sheet items, the loans from the central bank fully offset the banks' funding gaps, there are other characteristics that make the positions heterogeneous. First, in terms of pricing, the banks' funding has now shifted from cheaper retail deposits to more expensive central bank repos. Second, central bank repo financing is collateralised, which means that a relevant share of the banks' securities portfolios will become encumbered. Third, central bank financing is short-term and has to be rolled in the absence of alternative funding sources. By contrast, retail deposits, although in theory mostly callable on demand, are in practice the most stable source of bank funding (Gropp and Heider, 2010).

We then consider case B, where the rebalancing occurs via the actions of the commercial banks instead. Note that since the process involves transactions in debt securities rather than deposits, the macro-network considered in this case is drawn in the former instrument category. The main holding sectors are the investment funds (INV), MFIs (banks) and, as a result of the Eurosystem's extensive QE policies, the central bank. Instead, the central bank uses the resources it receives from the introduction of the CBDC to increase its holdings of debt securities. However, here the central bank also purchases bonds in proportion to its existing holdings. An alternative strategy would be akin to QE purchases, where acquisitions are made according to a pre-announced plan for different types of bonds; it is not unreasonable to assume that CBDC-related purchases would also follow some plan that the central bank could decide to make public. Overall, the differences in portfolio structures and rebalancing strategies across the sectors mean that in the rebalancing process the bonds that are subject to bids and those that are offered are not the same. The heterogeneous compositions of the commercial banks' and central bank's bond portfolios mean that some bonds will be subject to excess demand, while an excess of supply will occur for others, and market clearing will consequently require price adjustments. Figure 4 in Panel A illustrates the resulting imbalance between the supply of and demand for bonds, by sector. In the cases where supply from the commercial banks (the red bars) exceeds the demand from the central bank (the blue bars), the bond prices will fall, and vice versa in the cases where demand exceeds supply. Under the rules invoked in this stylised exercise, the bonds facing downward price pressure are those issued by the OFI, MFI, and ROW sectors. Conversely, the bonds facing upward price pressure are those issued by GOV and NFC sectors. Commercial banks are large holders of foreign debt instruments, while the CB usually refrains from such purchases in operations other than dedicated foreign exchange interventions. In our example, the excess supply of foreign bonds is likely to contribute both to a fall in their price and to a depreciation of the foreign currency vis-à-vis the domestic currency.

Then we consider Case C, where the commercial banks redeem loans to offset the loss of deposits. Based on the EAA data, in the network of loans the MFI, ROW and OFI sectors are the key nodes. The baseline assumption in such a "deleveraging scenario" is again that loans are redeemed proportionally, based on the current stock of loans extended by the banks to the other sectors (including interbank lending within the MFI sector itself). However, also in this case, plausible alternative scenarios can be envisaged, for example redemption decisions could be based on the risk characteristics of the loans. In that case, consumer credit and corporate SME loans would typically be redeemed first, owing to their higher historical loss characteristics. After proportional redemptions by the MFI, the sectors that are most affected are HH and NFC, which are the largest borrowers from the banks in the euro area financial system, followed by the GOV and ROW sectors. The borrowing sectors that lose part of their bank funding now face the choice of either shedding assets or seeking alternative funding sources. The latter can be either new loans extended by some other sector or debt securities issued by the sector itself. We assume that the sectors with access to debt capital markets – mainly the Government, NFC and ROW sectors – choose to issue new bonds, while the households sector reduces its existing bond holdings (assets) to offset the loss of bank financing. Panel B shows the supply-demand imbalances that arise in this case. Note that the demand side for debt securities is the same as in Panel A, because the central bank again rebalances its portfolio proportionally, given its existing mix of bond holdings. However, on the supply side, there are now both the debt securities sold by HH, which are bonds issued mainly by the GOV and MFI sectors, and the debt securities newly issued by mostly the NFC, OFI, ROW and GOV sectors. Combining the behavioural responses of all sectors, the bonds now facing most downward price pressure are those issued by the firms sector (NFC), while the bonds experiencing upward price pressure are those issued by ROW. The significant deterioration of the non-financial corporate sector funding situation in this case comes from two distinct sources. First, firms in the euro area rely heavily on bank loans as a funding source, and they are therefore strongly affected by the deleveraging of the commercial banks. Second, according to its portfolio structure, the central bank purchases only a relatively small portion of the non-financial corporate bonds that the firms issue in the subsequent period to substitute for the reduced lending by the commercial banks.

Finally, Panel C demonstrates the impact of Case D, where rebalancing takes the form of the commercial banks issuing new bonds and the CB increasing its bond holdings (different colors of the bar on the left side indicate the sector that could buy the newly issued bonds according to the current preferences). Because the entire supply of debt securities now consists of bank bonds, while the demand side is again split across various issuers according to the CB's current portfolio, market clearing requires a meaningful drop in the price of MFI bonds. According to the baseline rule of proportional purchases, the CB would absorb only around 12% of the newly issued bank bonds, while, based on its current portfolio structure, it would have the strongest demand for government bonds (65%).[10] In this scenario, the commercial banks therefore not only lose deposits to the CBDC in $t = 1$ but they also see an increase in their cost of market-based funding in $t = 2$, due to the limited capacity of the other sectors to absorb new MFI issuance.[11]

In discussing the potential risks of introducing a CBDC, Bindseil (2020) and Kumhof and Noone (2018) focus on the possibility of deposit runs in commercial banks and, to a lesser extent, the risk of disintermediation of the banks' lending activities. These prospects are also evident in our analysis if we scale up the size of the deposit shock.[12] However, our network approach allows us to unearth another vulnerability, which is the asymmetric price adjustment in marketable securities triggered by the rebalancing process. To minimise these distortions, the central bank has several options, each of which seem to represent a second-best solution compared to the current

[10]In the case of the Eurosystem, the Asset Purchase Programme (APP) has skewed the CB securities portfolio heavily in favour of government bonds. In addition, as regards MFI bonds, the Eurosystem rules currently allow purchases of covered bonds only. Other sectors, including the ROW, insurance companies, pension funds, investment funds and households, are the largest buyers of unsecured MFI bonds.

[11]The drop in bank bond prices that is necessary for the markets to clear implies an increase in yield, thus adding to the periodic coupon payments both on new debt and on the outstanding stock of debt.

[12]We look at this possibility in detail in Section 5.

system (but other perceived benefits from a CBDC may of course outweigh these losses). First, the central bank may lend the funds to the commercial banks, with the result, however, that this part of the banks' funding becomes collateralised, short-term and more expensive. Second, the CB could adjust its securities purchases to match as closely as possible the set of securities offered by the commercial banks (or by the sectors affected by the deleveraging of the commercial banks). In practice, this would mean increasing CB asset purchases of bonds issued by the private sector (especially MFI and NFC) and the rest of the world, which may prove controversial for the CB. Third, the CB could set up a loan portfolio for non-financial sectors with the aim of covering those borrowers most affected by the commercial banks' deleveraging. A legitimate question is whether the public sector possesses the skills and the information to price and risk-manage loans in a way that achieves a more efficient allocation of credit to society relative to the current allocation by the commercial banks.

#### *4.1.1. A Domestic Stablecoin Initiative*

Now consider the case where the digital currency is a stablecoin issued by a private domestic entity rather than the central bank. Such initiatives have been launched globally mainly as domestic payment projects that operate under a single jurisdiction or a single currency area.[13] In our framework the stablecoin issuer is incorporated into the investment funds sector (INV).

[13] These projects range from small local payment operators to vast and near-dominant players in digital payments, such as AliPay and WeChat in China. The natural advantage with tech companies in this area is their ability to combine a proprietary payments rail with existing online platforms which provide large user bases and the potential for significant network effects.

In Figure 13, the deposits that shift out of the commercial banks (the MFI sector, Panel B) are now directed to the investment funds sector as "non-MFI deposits" (Panel C). At $t = 2$, the deposit shift again triggers a rebalancing process. We consider four alternative scenarios:

i) *Case A.* The stablecoin issuer (INV sector) redeposits the funds with the MFI sector and places the deposits in its reserve fund (assets) to offset the increase in its deposit liabilities

ii) *Case B.* The MFI sells debt securities (assets) to offset the reduction in its deposit liabilities; the stablecoin (INV) purchases debt securities and places them in its reserve fund to offset the increase in its deposit liabilities

iii) *Case C.* The MFI redeems loans (assets) to offset the reduction in its deposit liabilities; the sectors which lose bank financing replace bank loans by issuing new debt securities; the stablecoin (INV) purchases debt securities and places them in its reserve fund to offset the increase in its deposit liabilities

iv) *Case D.* The MFI issues debt securities (liabilities) to offset the reduction in its deposit liabilities; the stablecoin (INV) purchases debt securities and places them in its reserve fund to offset the increase in its deposit liabilities

Case A is captured by Figure 5. The domestic stablecoin, which is part of the INV sector, redeposits the funds with the commercial banks (the MFI sector), as shown by the dark blue arrow now connecting the two sectors. The stablecoin reserve fund then consists of 100% commercial-bank deposits, and the rebalancing occurs without any action required by the MFI sector.

As a result, the INV sector becomes a key node in the network of deposits. The re-depositing of funds by the stablecoin with the commercial banks raises some questions, however. For example, there is a priori no way of guaranteeing that the banks that lost deposits at $t = 1$ are the same that will receive deposits from the stablecoin at $t = 2$, unless the allocation is made according to some kind of competitive bidding process. Another option is to route the process via the central bank, which offers these deposits in its tender operations according to demand by individual banks. In the cases where rebalancing takes the form of actions initiated by the commercial banks (the MFI sector) instead, the behavioural responses are similar to those in the case of the CBDC (see scenarios B-D Section 4.1). However, since the ultimate buyer of the debt securities is now the stablecoin (the INV sector), the purchases are made in proportion to its existing portfolio. Moreover, in this case, alternative rules could be considered. For example, the stablecoin issuer may want a reserve fund consisting of only cash-like securities, making the structure akin to a money market fund.

Figure 6 shows the results of scenarios B-D. Considering Case B, the network of debt securities changes when the stablecoin (INV sector) rebalances its reserve fund by purchasing bonds in proportion to the fund's existing holdings. Panel A shows the resulting supply/demand imbalances in the bond market. The prices of GOV, OFI and MFI debt securities will face downward pressure, while the prices of ROW and NFC debt securities will experience upward pressure.[14] Panel B displays results for Case C. After

[14] If the stablecoin reserve invested solely in cash-like assets, the GOV bonds would rise in price, whereas the prices of bonds issued by all other sectors would fall.

commercial banks have reduced lending proportionate to their loan portfolios, the rebalancing involves, on the supply side, both the HH sector selling debt securities and the other sectors issuing new bonds. Downward price adjustments will now be prevalent for the NFC, MFI, OFI, and GOV debt securities, while upward adjustments are limited to foreign (ROW) issued bonds. Panel C shows for scenario D, how the bond issuance of the banking sector is only partly offset by the purchases of the stablecoin (the INV sector). The resulting excess supply of bank bonds will only be absorbed by the other sectors if prices fall. This drop in prices of MFI bonds would be more substantial if the stablecoin had a mandate only to purchase government issued securities.

#### *4.1.2. A Global Stablecoin Initiative*

The stablecoin can also be set up as a global initiative. The difference compared to the domestic model is that the ROW sector now plays a key role, with the relative importance of the domestic investment funds sector depending on the weight of the domestic economy in the stablecoin vehicle's global reserve fund. Some observers have suggested that a global stablecoin whose reserve fund is denominated in a (mix of) foreign currencies could be considered a currency board type arrangement (see Anderson and Papadia, 2020). For the analysis below, adopting this analogy would make no difference in theory but since currency boards are not a concept that is included in either the national accounts or the regulatory classifications, we consider the global private digital currency/stablecoin a non-MFI deposit scheme. Figure 14 illustrates the case, with Panel A showing the network of deposits after 20% MFI deposit withdrawals by the HH and NFC sectors. In Panel B, the funds are transferred to the ROW sector where the stablecoin issuing vehicle now resides. Panel C shows the final step in $t = 1$, where the global stablecoin vehicle moves a share of $\gamma$ of its globally acquired deposits from the ROW (its home jurisdiction) back to the domestic financial system (the host jurisdiction from the global stablecoin's perspective), where $\gamma$ denotes the weight of the domestic currency in the stablecoin's global reserve fund. In the simulations, it is assumed that this weight equals 30.93%, which is the current weight of the EUR in the IMF's SDR basket. The domestic subsidiary of the global stablecoin is placed within the domestic Investment Funds sector (INV). The rebalancing process must now take into account that the funds withdrawn from the commercial banks' deposit accounts are split between two sectors. The share of $\gamma$ will go to the global stablecoin's domestic subsidiary (placed in the INV sector), whereas the share of $1 - \gamma$ will move to the ROW. The familiar options, A) to D), for rebalancing are now somewhat changed. Figure 15 shows option A), where the domestic INV sector first redeposits its share of $\gamma$ with the domestic commercial banks (the MFI sector), leaving the MFIs with a remaining funding gap of $1-\gamma$ (Panel A). The ROW sector goes through its own internal rebalancing process, but at the end of the day, it will hold $1 - \gamma$ worth of surplus EUR denominated funds, which it will deposit in the domestic CB. In the case of the Eurosystem, these funds would go under the balance sheet item "EUR denominated deposits by non-euro area residents" (Panel B). The domestic commercial banks then borrow these funds from the central bank in its repo operations to cover their remaining funding gap (Panel C).

Cases B-D are similar to those described in Sections 4.1 and 4.1.1, with the difference being that if, for example, the MFI sector issues new bonds, these bonds cannot be purchased by the ROW sector, since the latter will not acquire euro area assets in excess of its share of $1 - \gamma$. However, given that in a closed financial system the ROW sector ultimately redeposits its share of $1-\gamma$ with the domestic central bank, in cases B to D the securities purchases are made jointly by the CB and the INV sectors, with the relative shares determined by the size of $\gamma$. Figure 11 shows the ratio between demand and supply in debt securities for case B as a function of $\gamma$, with $\gamma = 0$ corresponding to the CBDC framework and $\gamma = 1$ to the domestic stablecoin initiative. The graph highlights that depending on the level of $\gamma$ the price impact may vary substantially especially for the government bond segment.

## 5. Comparative Statics

In this section, we provide further analysis to quantify the economic impact caused by the introduction of the digital currency. We also consider network metrics and explore the implications of introducing a digital currency at the different point in time.

### *5.1. Banks' Funding*

Retail deposits are a key source of funding for commercial banks (MFI). It is therefore important to evaluate the broader impact on banks of the deposit shift triggered by the introduction of a digital currency. For this, we define $Funding-shock_{MFI}$ as the ratio between the amount that is withdrawn by corporate and household depositors, the shock $\varepsilon$, and the total amount of deposits held by all sectors with commercial banks:

$$Funding-shock_{MFI} = \frac{D_{MFI,NFC} + D_{MFI,HH}}{D^L_{MFI}} \tag{1}$$

Table 1, column 2 shows the overall impact of the withdrawals on commercial bank deposits, expressed in percentages. In turn, columns 3 and 4 show the respective contributions of the NFC and HH sector withdrawals to the total impact. Under the baseline scenario, where the private non-financial sectors each withdraw 20% of their bank deposits, the negative impact on the overall MFI deposit stock is limited to around 9%. Household depositors are the main contributors to this loss. When the size of the deposit shock increases, the overall loss of commercial bank funding also increases. Setting the shock at 80% of both NFC and HH deposits would cause a loss of 37% of all commercial bank deposits. Such a large outflow would require far more significant rebalancing and possibly a large-scale recourse to central bank lending facilities at time $t = 2$. Columns 5 and 6 show the results of a scenario in which also the ROW sector shifts a share of deposits to a digital currency. In this case the funding shock for MFI would raise to almost 49%. While it might be unreasonable to expect shifts of such magnitude to occur in short periods of time, the exercise nevertheless highlights the importance of the pace and magnitude of the digital currency's potential ability to capture market share in deposits. That said, in the low (even negative) interest rate environment and with younger customers less loyal to traditional banking services, significant changes in deposit patterns may take place if digital currencies were to prove particularly convenient or if they provided additional functions that are appealing to depositors.

### *5.2. The Impact of MFI Rebalancing Strategies*

Next, we explore how sectors are affected by commercial banks' rebalancing actions at time $t = 2$. We consider two separate MFI rebalancing strategies, where banks can either sell debt securities or redeem loans. We define the impact on sector $i$, $B - Impact_i$, as the ratio between the bonds issued by sector $i$ that are sold by the MFI and the total outstanding amount of bonds issued by sector $i$. This measure provides, for all debt issuing sectors, an indicator of the funding constraints (due to both the downward pressure on bond prices and/or the difficulties in placing new bonds) that would arise in the absence of a corresponding increase in demand by some other sector in the system.

$$B - Impact_i = \frac{Sold - B^A_{i,MFI}}{B^A_i} \tag{2}$$

To account for the amount of loans that could be redeemed in the MFI rebalancing process, we define $C - Impact_i$ as the ratio between the loans extended by banks to sector $i$ but redeemed following the shock and the total outstanding amount of loans extended to sector $i$. The ratio provides a measure of the loan-funding gap for each sector in the absence of new lending by some other sector in the system.

$$C - Impact_i = \frac{Redeemed - C_{i,MFI}}{C^L_i} \tag{3}$$

Figure 8 displays this impact of banks' rebalancing strategies for different shock sizes. Panel A shows that the most affected sectors when the banks sell debt securities are the MFI itself, OFI, GOV and ROW. Panel B shows that if the banks redeem loans instead, the most affected sectors are HH, NFC, INV and GOV. Under the baseline scenario of a 20% deposit withdrawal by both HH and NFC, even the most affected sectors would experience a relatively limited impact; for example $B - Impact_{OFI}$ would amount to 11% and $C - Impact_{HH}$ to 12%. However, if the size of the deposit shift rises to 50%, almost 30% of all outstanding OFI debt securities would be sold or, alternatively, some 30% of all loans extended to HH would be redeemed.[15]

### 5.3. Changes in the Macro-Network Structure

We now turn to an investigation of how the structures of the macro-networks change when the size of the shock is allowed to vary. To do this, we first introduce closeness, a network centrality measure that allows us to quantify the changes in the networks that are triggered by the introduction of the digital currency and the rebalancing process that follows it. Measures of network centrality quantify the position of a given node in the network and provide insights into contagion and diffusion processes. They have been used to investigate the effect of the global financial crisis on the interbank market (Affinito and Pozzolo, 2017), the dynamics of the global banking network (Minoiu and Reyes, 2013) and the relationship between international trade linkages and stock market returns (Kali and Reyes, 2010).[16] We apply closeness as a measure of how "close" a node is to all the other nodes in the network. Even if the macro-networks considered here consist of only 10 nodes (institutional sectors), closeness can provide indications of how the importance of each sector in the system changes.[17] We focus on the case where the digital currency is classified as a deposit scheme and issued by either CB or INV. Drawing from the network of deposits, Figure 9 shows

[15] Additional analysis concerning the impact on the other sectors of MFI rebalancing would include different strategies followed by the MFI (see Section 4.1), which do not report for the sake of brevity.

[16] Other applications include analysis of venture capital firms and fund performance (Hochberg et al., 2007), the effect of CEOs' social connections on M&A outcomes (El-Khatib et al., 2015), and other corporate finance policy decisions (Fracassi, 2017).

[17] We consider the weighted version of closeness to properly take into account changes in the intensity of the financial linkages.

how the closeness measure of the interested sectors varies with the size of the shock in the case of a CBDC (Panels A and B) and in the case of a stablecoin (Panels A and C) across the different simulation stages. Following the introduction of the CBDC, Panel B shows the growing centrality of the central bank as the shock size increases. CB centrality then decreases as the shock size rises after rebalancing at time $t = 2$, but it does not reach the pre-shock level. Panel C shows similar patterns for the INV sector (stablecoin). In both cases, the centrality of the MFI sector is lower at $t = 2$ than at $t = 0$ (Panel A). Importantly, this proves that even in the most conservative scenario, where the MFI borrows the lost deposits back from the digital currency issuing sector, the relative importance of the different sectors and the structure of the "steady state" macro-network change.

### *5.4. Introduction of Digital Currency Over Time*

Finally, we explore the effects of the introduction of a digital currency over time. The time series covers the period for which data from the who-to-whom accounts are available, i.e. from Q1 2015 to Q1 2019. As a first step, using the metrics introduced in Section 5.1, in Figure 10 we consider the overall funding impact for MFI after a 20% deposit shock from the NFC and HH sectors (red line) and NFC, HH and ROW sectors (blue line). We notice an increase in the relative contribution of the deposit shift by the NFC sector from 1.9% in Q1 2015 to 2.2% in Q1 2019, and by the HH sector from 6.5% in Q1 2015 to 6.9% in Q1 2019. The overall impact on MFI deposits of the deposit withdrawal by the private non-financial sectors rises from 8.4% to 9.1%, while when we consider also the ROW it increases from 11.4% to 12.2%. The overall growth in impact is not particularly large, but the graph nonetheless highlights how the timing of the introduction of the digital currency could be relevant as the impact is clearly time-varying. Similarly, the effects of MFI rebalancing strategies on funding shortage for the different sectors of the economy also vary and should be taken into account by policy makers and regulators. Another important feature varying over time is the impact on the different segment of the debt market. We apply our assumptions that MFI sell bonds keeping exposures to different sectors constant, and, similarly, CB (or INV) target bonds purchases maintaining fixed the exposures to different sectors in percentage terms at each point in time. We then plot the pattern of time of the ratio between demand and supply in debt securities for case B of the CBDC framework. Figure 11a shows that as exposures of MFI and CB differ over time different impact in term of downward and upward price pressure could be foreseen.

Network centrality measures illustrate the evolution over time of the shape of the macro-network. Figure 12 focuses on the dynamic pattern of centrality of three sectors (CB, MFI and ROW) that in the network of deposits at $t = 0$ were the most central. While the centrality of both the MFI and ROW sectors has decreased over time, the centrality of the central bank has increased dramatically throughout the past four years, again reflecting the Eurosystem asset purchase programmes. Network structures may therefore change significantly even over a relatively short period of time, which means that "time 0", when the digital currency is to be launched, could indeed matter. This is because, as was shown earlier in this paper, the ultimate impact of the introduction of a digital currency and the rebalancing that follows it are dependent on the underlying network structures. At certain times and under certain conditions, a digital currency could therefore be more disruptive.

## 6. Conclusion

This paper applied the network approach to financial accounts to study the broader implications of the introduction of digital currencies. The network approach provides important additional insights into the adjustment processes that may follow from the large-scale adoption of major financial innovations. The following sequence of key points summarises our contribution. (i) Design: the way the digital currency scheme is established (public or private issuer and the classification) makes a difference both for the issuing sector, the banking sector, the retail users/depositors and the monetary/regulatory authorities. Specific circumstances may favour certain designs over others. (ii) Reaction: The ways the affected parties adjust to the introduction of the digital currency by shifting deposits and rebalancing their accounts depend not only on (i) but also on the incentives and constraints/mandates they face. There may be ways to shape these incentives by mechanism design and public policy. (iii) Third parties: Given that the financial system is a network exposures, third parties will be affected by the introduction of a digital currency and the rebalancing that follows it. The identity of these third parties and the impact they experience may differ depending on how (i) and (ii) play out. Effort should be taken to identify the relevant links and mitigate any potential collateral damage ex ante. (iv) Timing: The financial network structures that in part determine (i), (ii) and (iii) are not static; rather, they evolve over time as the intensity of the bilateral links change. This means that, at any point in time, the network may be more or less able to absorb shocks, and therefore the timing of the initiative also matters.

Our results underline the importance of the full network implications of innovations for financial intermediation. Any shock to the system that causes shifts in the financial balance sheets have the potential to generate a redistribution of financial linkages and forcing adjustments in financial asset prices which may not be properly captured by analysis that does not consider the full network of interlinked exposures. We also stress that from financial stability perspective, it is important to focus on the impact on the asset side of financial institutions and the associated risks for non-financial sectors, as well as the strong cross-border linkages inherent in financial networks.

## References


Acemoglu, D., Akcigit, U., Kerr, W., 2016. Networks and the macroeconomy: An empirical exploration. NBER Macroeconomics Annual 30, 273–335.

Adrian, M.T., Griffoli, M.T.M., 2019. The rise of digital money. International Monetary Fund.

Adrian, T., Shin, H.S., 2010. Liquidity and leverage. Journal of financial intermediation 19, 418–437.

Affinito, M., Pozzolo, A.F., 2017. The interbank network across the global financial crisis: Evidence from italy. Journal of Banking & Finance 80, 90–107.

Agur, I., Ari, A., Dell'Ariccia, G., 2019. Designing central bank digital currencies .

Aldasoro, I., Alves, I., 2018. Multiplex interbank networks and systemic importance: an application to european data. Journal of Financial Stability 35, 17–37.

Allen, F., Gale, D., 2000. Financial Contagion. Journal of Political Economy 108, 1–33. doi:10.1086/262109.

Anderson, J., Papadia, F., 2020. Libra as a currency board: are the risks too great? URL: `https://www.bruegel.org/2020/01/libra-as-a-currency-board-are-the-risks-too-great/`.

Andolfatto, D., 2018. Assessing the impact of central bank digital currency on private banks. FRB St. Louis Working Paper .

Bargigli, L., Di Iasio, G., Infante, L., Lillo, F., Pierobon, F., 2015. The multiplex structure of interbank networks. Quantitative Finance 15, 673–691.

Bindseil, U., 2020. Tiered cbdc and the financial system .

Brunnermeier, M.K., James, H., Landau, J.P., 2019. The digitalization of money. Technical Report. National Bureau of Economic Research.

Brunnermeier, M.K., Niepelt, D., 2019. On the equivalence of private and public money. Journal of Monetary Economics 106, 27–41.

Bullmann, D., Klemm, J., Pinna, A., 2019. In search for stability in crypto-assets: Are stablecoins the solution? ECB Occasional Paper .

Caccioli, F., Shrestha, M., Moore, C., Farmer, J.D., 2014. Stability analysis of financial contagion due to overlapping portfolios. Journal of Banking & Finance 46, 233–245.

Castrén, O., Kavonius, I.K., 2013. Balance sheet interlinkages and macro-financial risk analysis in the euro area, in: Fouque, J.P., Langsam, J.A. (Eds.), Handbook on Systemic Risk. Cambridge University Press, pp. 775–789.

Castrén, O., Rancan, M., 2014. Macro-networks: An application to euro area financial accounts. Journal of banking & finance 46, 43–58.

Craig, B., Von Peter, G., 2014. Interbank tiering and money center banks. Journal of Financial Intermediation 23, 322–347.

El-Khatib, R., Fogel, K., Jandik, T., 2015. Ceo network centrality and merger performance. Journal of Financial Economics 116, 349–382.

Fernández-Villaverde, J., Sanches, D., Schilling, L., Uhlig, H., 2020. Central Bank Digital Currency: Central Banking For All? Technical Report. National Bureau of Economic Research.

Fracassi, C., 2017. Corporate finance policies and social networks. Management Science 63, 2420–2438.

Gai, P., Kapadia, S., 2010. Contagion in financial networks. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 466, 2401–2423.

Glasserman, P., Young, H.P., 2015. How likely is contagion in financial networks? Journal of Banking & Finance 50, 383–399.

Greenwood, R., Landier, A., Thesmar, D., 2015. Vulnerable banks. Journal of Financial Economics 115, 471–485.

Gropp, R., Heider, F., 2010. The determinants of bank capital structure. Review of finance 14, 587–622.

Hochberg, Y.V., Ljungqvist, A., Lu, Y., 2007. Whom you know matters: Venture capital networks and investment performance. The Journal of Finance 62, 251–301.

IMF, 2018. How to deal with bitcoin and other cryptocurrencies in the system of national accounts?

Kali, R., Reyes, J., 2010. Financial contagion on the international trade network. Economic Inquiry 48, 1072–1101.

Keister, T., Sanches, D., et al., 2019. Should Central Banks Issue Digital Currency? Technical Report. Federal Reserve Bank of Philadelphia.

Kim, Y.S., Kwon, O., 2019. Central bank digital currency and financial stability. Bank of Korea WP 6.

Kumhof, M., Noone, C., 2018. Central bank digital currencies-design principles and balance sheet implications .

Minoiu, C., Reyes, J.A., 2013. A network analysis of global banking: 1978–2010. Journal of Financial Stability 9, 168–184.

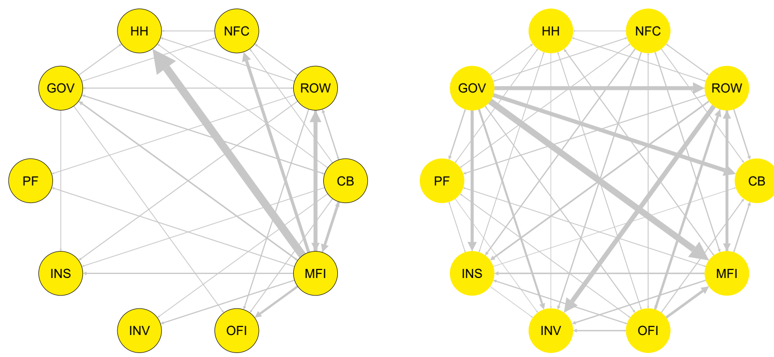
Mistrulli, P.E., 2011. Assessing financial contagion in the interbank market: Maximum entropy versus observed interbank lending patterns. Journal of Banking & Finance 35, 1114–1127.

OECD, 2018. Treatment of crypto assets in macroeconomic statistics.

Peltonen, T.A., Scheicher, M., Vuillemey, G., 2014. The network structure of the cds market and its determinants. Journal of Financial Stability 13, 118–133.

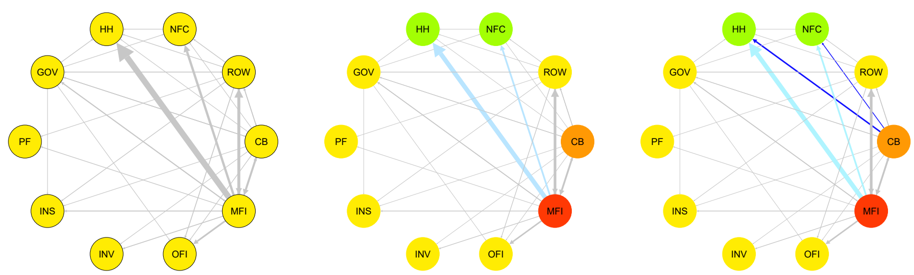
Poledna, S., Molina-Borboa, J.L., Martínez-Jaramillo, S., Van Der Leij, M., Thurner, S., 2015. The multi-layer network nature of systemic risk and its implications for the costs of financial crises. Journal of Financial Stability 20, 70–81.

Upper, C., Worms, A., 2004. Estimating bilateral exposures in the German interbank market: Is there a danger of contagion? European Economic Review 48, 827–849. doi:10.1016/j.euroecorev.2003.12.009.




(Panel A: Deposits) (Panel B: Debt Securities)

Figure 1: Examples of Macro-Networks in Two Categories of Financial Instruments. Panel A: Network of deposits; Panel B: Network of debt securities. Arrows run from liabilities to assets.




(Panel A) (Panel B) (Panel C)

Figure 2: Central Bank Digital Currency: Network of Institutional Sectors, Instrument Deposits, $t = 1$. Panel A: Network of deposit as they are in the data; Panel B: Network of deposits after NFC and HH have withdrawn 20% of their deposits; Panel C: Network of deposits after NFC and HH have invested funds in CBDC.

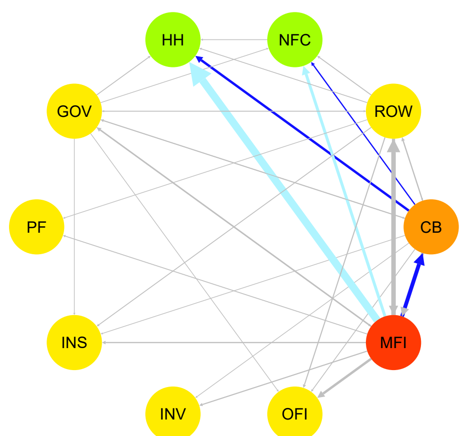
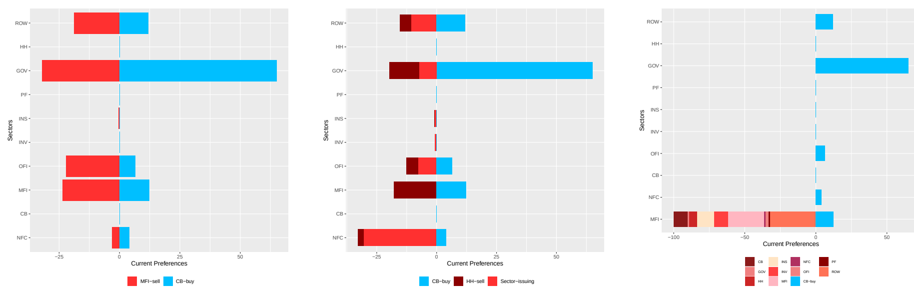



Figure 3: Central Bank Digital Currency: Network of Institutional Sectors, Instrument Deposits, $t = 2$, Case A. Network of deposits after CB redeposits funds at MFI.




(Panel A) (Panel B) (Panel C)

Figure 4: Central Bank Digital Currency: Supply-demand imbalance in debt securities across individual sectors, $t = 2$. The graphs show the supply-demand imbalance in debt securities across individual sectors for cases B (Panel A), C (Panel B), D (Panel C). In Panels A-C blue bars represent the debt securities that CB would buy to keep its exposures constant. In Panel A red bars represent the debt securities that MFI would sell) to keep its exposures constant. In Panel B dark red bars represent the debt securities that HH would sell and red bars represent the amount of new debt issuance to offset MFI redemption of loans. In Panel C the bar on the left corresponds to the new debt issuance by MFI, splitted according to the sectors holding the existing MFI bonds. All values are normalized and expressed in percentage terms.

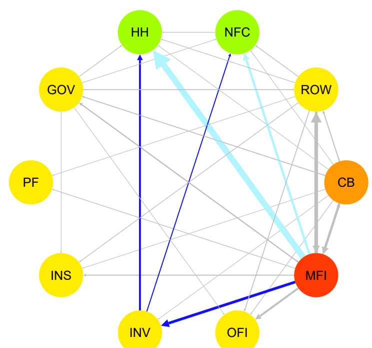
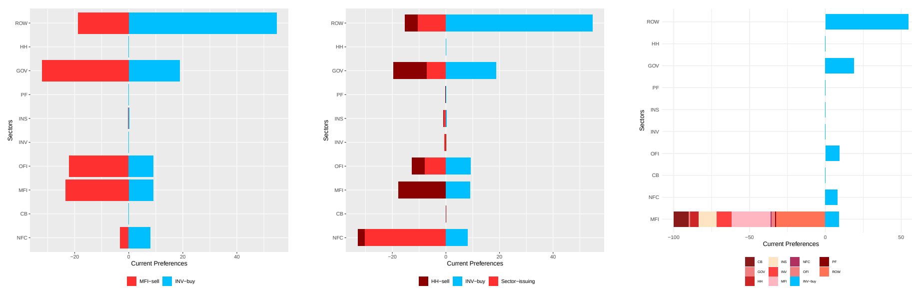



Figure 5: Domestic Stablecoin Initiative: Network of Institutional Sectors, Instrument Debt Securities, $t = 2$, case A.




(Panel A) (Panel B) (Panel C)

Figure 6: Domestic Stablecoin Initiative: Supply-demand imbalance in debt securities across individual sectors, $t = 2$. The graphs show the supply-demand imbalance in debt securities across individual sectors for cases B (Panel A), C (Panel B), D (Panel C). In Panels A-C blue bars represent the debt securities that INV would buy to keep its exposures constant. In Panel A red bars represent the debt securities that MFI would sell to keep its exposures constant. In Panel B dark red bars represent the debt securities that HH would sell and red bars represent the amount of new debt issuance to offset MFI redemption of loans. In Panel C the bar on the left corresponds to the new debt issuance by MFI, splitted according to the sectors holding the existing MFI bonds. All values are normalized and expressed in percentage terms.

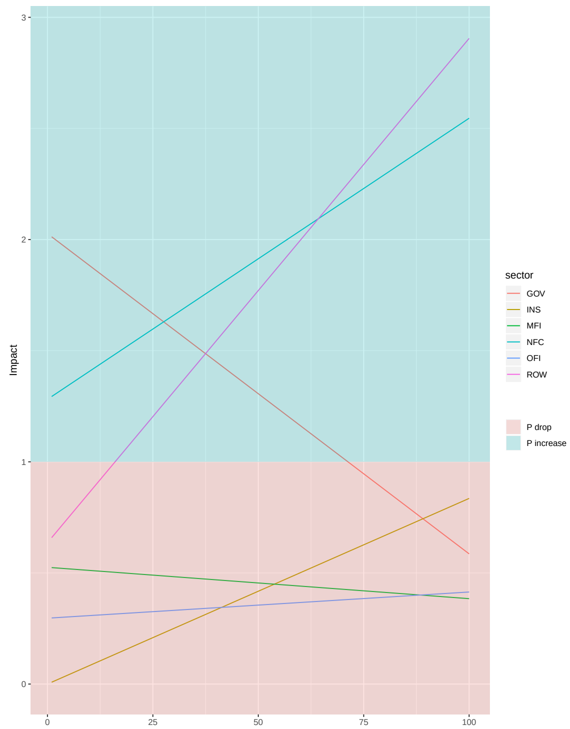
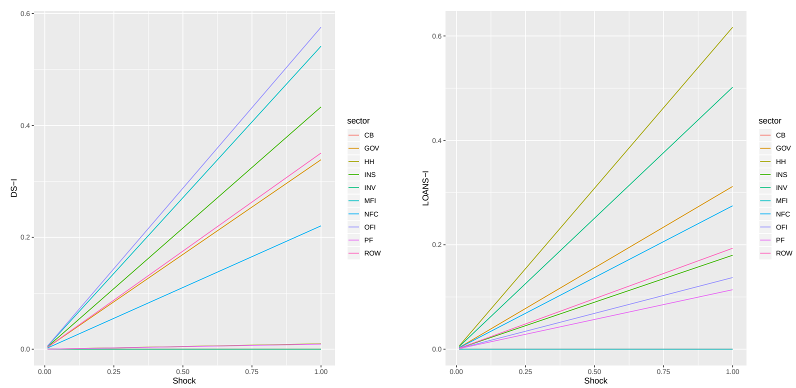
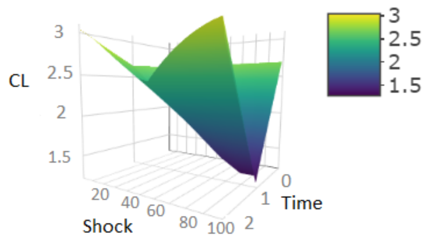



Figure 7: Impact on debt securities as a function of gamma: $y - axis$ represents the ratio between demand and supply in debt securities for each sector varying $\gamma$ ($x - axis$). The case represented is B, MFI sell debt securities, and CB buy debt securities ($\gamma = 0$) or INV buy debt securities ($\gamma = 1$). In the blue (red) area prices undergo a upward (downward) pressure.

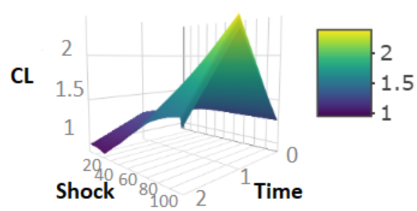



(Panel A) (Panel B)

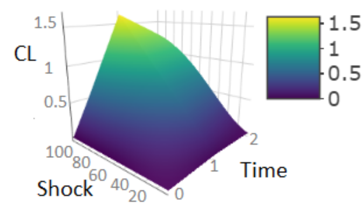
Figure 8: Impact of MFI Rebalancing Strategies for Different Shock Sizes. Panel A shows the ratio between the debt securities issued by sector $i$ and sold by the MFI, and the total outstanding amount of debt securities issued by sector $i$. Panel B shows the ratio between the amount of loans extended to sector $i$ and redeemed by MFI, and the total outstanding amount of loans extended to sector $i$. The horizontal axis refers to the size of the shock $\varepsilon$ (from 0% to 100%).




(Panel A: MFI)




(Panel B: CB)




(Panel C: INV)

Figure 9: Sector Centrality Measures at Different Simulation Stages. The network under investigation is the one of deposits, the centrality measure is closeness (normalized). Panel A refers to MFI, Panel B to CB (the case of the CBDC), and Panel C to INV (the domestic stablecoin initiative). The $x-axis$ measures the size of the shock. The $y-axis$ depicts the scale of the centrality measure (closeness). The $z-axis$ shows time.

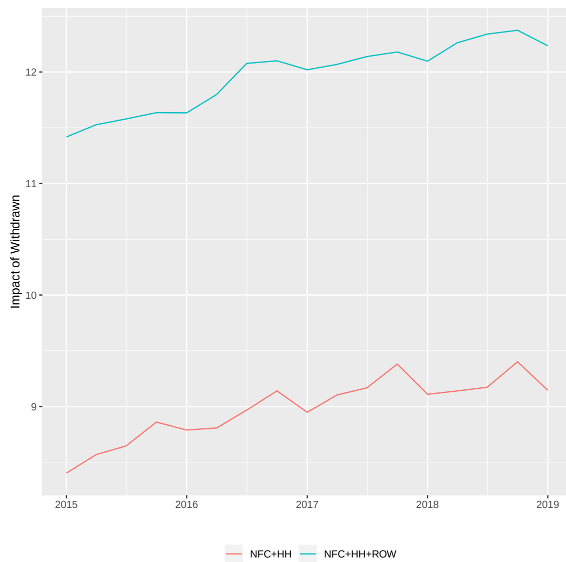



Figure 10: Impact of Deposit Shift on MFI over time. The chart shows, over time, the ratio between a 20% deposit withdrawal by the NFC and HH sectors and total MFI deposits (red line), and a 20% deposit withdrawal by the NFC, HH and ROW sectors and the total MFI deposits (blue line). Period Q1 2015-Q1 2019. All values are in percentages.

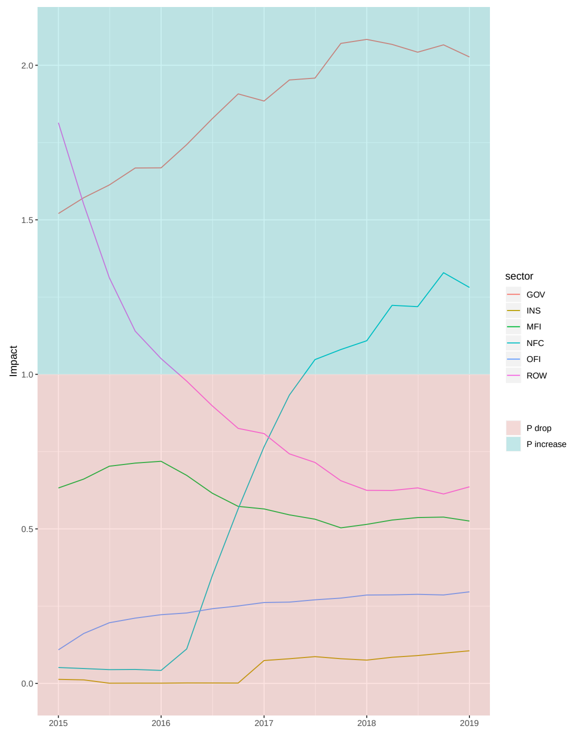
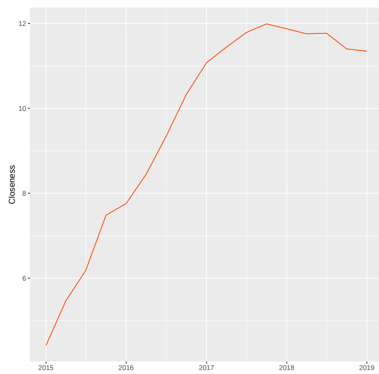
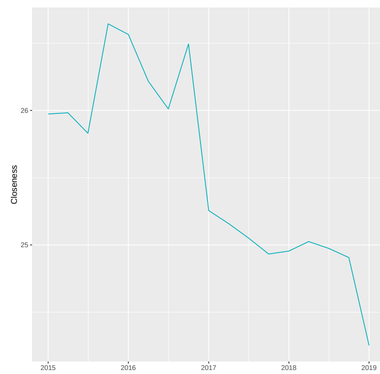


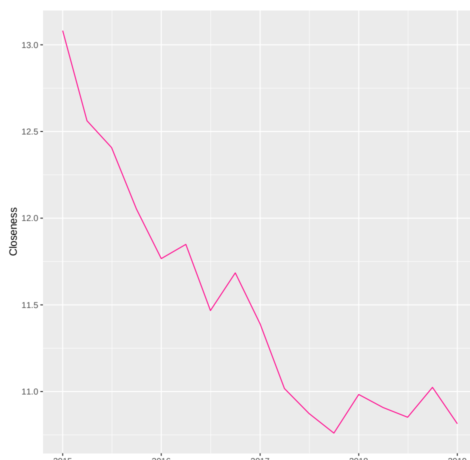

Figure 11: Impact on debt securities over time. $y - axis$ represents, over time, the ratio between demand and supply in debt securities for each sector. The framework is the central Bank Digital Currency considered case B (MFI sell debt securities, and CB buy debt securities). Period Q1 2015-Q1 2019. In the blue (red) area prices undergo a upward (downward) pressure.




(Panel A: CB)




(Panel B: MFI)




(Panel C: ROW)

Figure 12: Sector Centrality Measures over Time. The charts show the values of closeness for the CB (Panel A), MFI (Panel B), and ROW (Panel C) over time. The network under investigation is the one of deposits, the centrality measure is closeness (normalized). Period Q1 2015-Q1 2019.

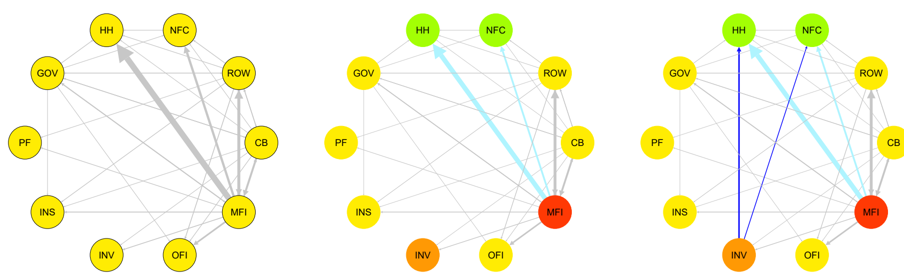
Table 1: Impact of Deposit Shift on MFI. The table shows the deposit shift as a % share of the depositing sector's MFI deposits (column 1), the overall reduction in MFI deposits (column 2), and the contributions of NFC (column 3) and HH (column 4) to the total reduction in deposits. Funding shocks for the case in which also RoW shifts some deposits are shown in columns 5-6. All values are in percentages.

| $\% of \varepsilon$ | Funding-shock$_{MFI}$ | Funding-shock$_{MFI,NFC}$ | Funding-shock$_{MFI,HH}$ | Funding-shock$_{MFI}$ | Funding-shock$_{MFI,ROW}$ |
|---|---|---|---|---|---|
| 10 | 4.57 | 1.12 | 3.46 | 6.12 | 1.54 |
| 20 | 9.15 | 2.23 | 6.91 | 12.23 | 3.09 |
| 30 | 13.72 | 3.35 | 10.37 | 18.35 | 4.63 |
| 40 | 18.29 | 4.47 | 13.83 | 24.47 | 6.18 |
| 50 | 22.86 | 5.58 | 17.28 | 30.59 | 7.72 |
| 60 | 27.44 | 6.70 | 20.74 | 36.70 | 9.27 |
| 70 | 32.01 | 7.82 | 24.19 | 42.82 | 10.81 |
| 80 | 36.58 | 8.93 | 27.65 | 48.94 | 12.36 |
| 90 | 41.16 | 10.05 | 31.11 | 55.06 | 13.90 |
| 100 | 45.73 | 11.16 | 34.56 | 61.17 | 15.44 |

## Appendix

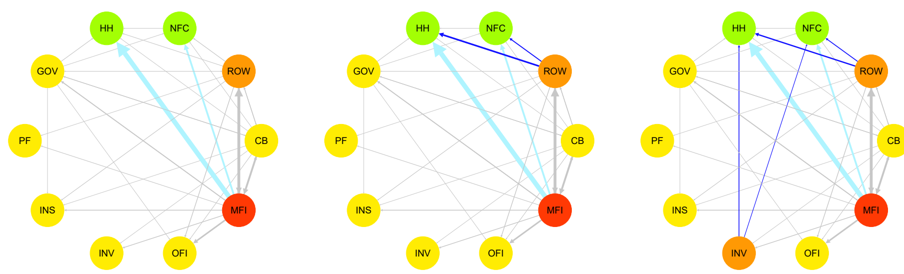
This appendix includes the graphs of institutional sectors to show the changes in the macro-network in:

- a domestic stablecoin initiative (Figure 13);
- a global stablecoin initiative (Figure 14 for $t = 1$ and Figure 15 for $t = 2$).



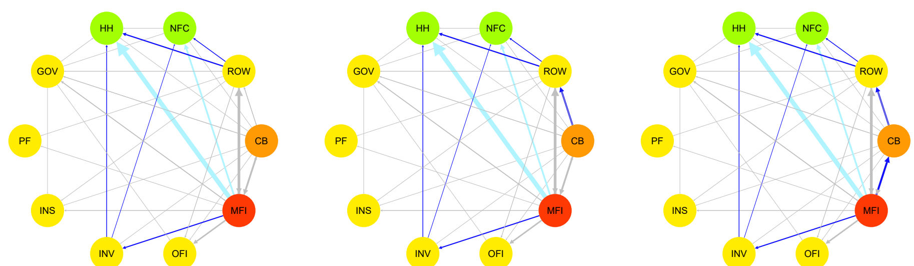

(Panel A) (Panel B) (Panel C)

Figure 13: Domestic Stablecoin Initiative: Network of Institutional Sectors, Instrument Deposits, $t = 1$. Panel A: Network of deposit as they are in the data; Panel B: Network of deposits after NFC and HH have withdrawn 20% of their deposits; Panel C: Network of deposits after HH and NFC have shifted the deposits to an INV (domestic stablecoin).




(Panel A) (Panel B) (Panel C)

Figure 14: Global Stablecoin Initiative: Network of Institutional Sectors, Instrument Deposits, $t = 1$. Panel A: Network of deposits after NFC and HH have withdrawn 20% of their deposits; Panel B: Network of deposits after the deposits withdrawn have been moved to the ROW sector (the foreign home sector); Panel C: Network of deposits after the global stablecoin has re-invested a share of $\gamma$ of its global funds in the euro area investment funds sector (the domestic host sector).




(Panel A) (Panel B) (Panel C)

Figure 15: Global Stablecoin Initiative: Network of Institutional Sectors, Instrument Deposits, $t = 2$, Case A. Panel A: Network of deposits after INV has redeposited a share $\gamma$ of the funds with the MFI sector; Panel B: Network of deposits after ROW has deposited a share of $1 - \gamma$ with the domestic CB; Panel C: Network of Deposits after the MFI has borrowed $1 - \gamma$ from the CB to cover the remaining funding gap.