CAHIER D'ÉTUDES
WORKING PAPER

N° 155

THE ONE TRILLION EURO DIGITAL CURRENCY:
How to issue a digital euro without threatening monetary policy transmission and financial stability?

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AUGUST 2021

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

The One Trillion Euro Digital Currency:

How to issue a digital euro without threatening monetary policy transmission and financial stability?

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August 2021

Abstract: The introduction of a general-purpose central bank digital currency (CBDC) carries the risk of bank disintermediation, potentially jeopardizing financial stability and monetary policy transmission through the bank lending channel. By adapting the theoretical framework of Dutkowsky and VanHoose (2018b, 2020) to the euro area, this study clarifies the conditions under which a digital euro could be introduced on a large scale without leading to bank disintermediation or a credit crunch. First, the central bank would need to set up proper mechanisms to manage the volume and the user cost of CBDC in circulation. Second, since some bank deposits will be converted into CBDC, the central bank should continue to facilitate access to its long-term lending facilities in order to provide banks with an alternative funding source at an equivalent cost. Depending on its design, a digital euro could improve bank profitability by absorbing large amounts of idle (and expensive) excess reserves without penalizing lending. A digital euro could also improve banks' competitive position relative to non-bank lenders and encourage bank digitalization.

***JEL* Classification**: E41, E42, E51, E52, E58, G21

Keywords: Central bank digital currency, cash, central bank, monetary policy, excess reserves, reserve requirements, universal central bank reserves, bank deposits, bank profitability, bank credit, inside money, collateral

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Résumé non-technique

En octobre 2020, la Banque centrale européenne a publié un rapport examinant *l'euro numérique*, une forme électronique de monnaie de banque centrale qui pourrait être accessible à tous les citoyens et entreprises pour les transactions de détail. L'introduction d'une telle monnaie numérique de banque centrale (en anglais : *central bank digital currency* ou *CBDC*) pourrait devenir indispensable sous plusieurs scenarios. Cependant, elle pourrait également entraîner une désintermédiation bancaire, avec des effets indésirables pour la stabilité financière et la transmission de la politique monétaire par le canal du crédit. En effet, si les banques centrales permettent aux clients bancaires d'échanger une partie substantielle de leurs dépôts contre des CBDC, cela pourrait faciliter des retraits massifs en cas de panique bancaire. Même en temps normal, les banques commerciales pourraient se trouver privées d'une source importante de financement bon marché, ce qui pourrait les inciter à réduire leurs prêts et leurs bilans, avec des répercussions négatives sur l'activité économique et l'inflation.

Cette étude vise à développer un cadre théorique réaliste afin d'analyser l'impact qu'aurait l'introduction de l'euro numérique sur les banques. Elle met en évidence deux conditions essentielles pour éviter une désintermédiation bancaire ou un resserrement du crédit. Premièrement, la banque centrale devrait disposer de mécanismes appropriés pour contrôler le volume de CBDC en circulation. Cela lui permettrait de garder le contrôle de la politique monétaire, tout en évitant une contraction des réserves bancaires qui pourrait compromettre l'efficacité des politiques monétaires non conventionnelles. Étant donné que le niveau actuel de liquidité excédentaire s'élève à 4 335 milliards d'euros, une estimation prudente, calibrée sur les conditions d'avant la crise, suggère qu'un peu plus de mille milliards d'euros pourraient être émis en tant que CBDC. L'analyse examine deux instruments pour gérer les volumes de CBDC sans imposer de plafonds stricts : *i)* un instrument direct tel que le taux de rendement global de la CBDC (frais et charges inclus), et *ii)* un mécanisme indirect basé sur les réserves obligatoires des établissements de crédit.

Deuxièmement, la banque centrale devrait continuer à favoriser l'accès à ses facilités de prêt à long terme afin de permettre aux banques dont les réserves sont limitées de compenser l'érosion des dépôts de la clientèle, convertis en CBDC, par une autre source de financement au même coût. Ceci impliquerait le maintien de mesures qui sont déjà en place dans la zone euro depuis plus d'une décennie et dont l'utilisation s'est encore étendue au cours de la pandémie. Dans ces conditions, les banques compenseraient la baisse des dépôts par des emprunts auprès de la banque centrale, et ne devraient ainsi avoir aucune raison de réduire leurs volumes de prêts. De plus, les banques disposant de réserves excédentaires suffisantes pour couvrir la réduction des dépôts pourraient voir leur rentabilité augmenter proportionnellement. Quant aux banques jouant le rôle d'agents et de « points d'accès » à la CBDC, elles bénéficieraient d'une occasion unique d'améliorer leur situation concurrentielle par rapport aux prêteurs non bancaires, facilitant leur transition vers un nouveau modèle d'affaires plus conforme à l'économie numérique du XXIe siècle.

Au niveau macroéconomique, le concept de CBDC ici proposé devrait non seulement permettre d'éviter la désintermédiation massive des banques, mais aussi l'abandon des espèces comme instrument de paiements et surtout comme réserve de valeur. En outre, une plus grande partie de

base monétaire se trouverait en dehors du système bancaire, ce qui réduirait la variabilité de la masse monétaire au bénéfice de la stabilité financière.

Dans le cadre de la mise en œuvre de la politique monétaire, étendre l'accès au bilan de la banque centrale pourrait fournir un moyen plus direct d'influencer les conditions de l'économie réelle. En contrôlant le volume et le coût d'utilisation de la CBDC, la banque centrale disposerait d'un outil efficace pour mieux gérer la liquidité du système bancaire. Dans la zone euro, la conception de la CBDC devrait aussi tenir compte de la répartition hétérogène des réserves excédentaires entre les banques des différents pays. Cela ne devrait pas représenter un obstacle majeur à l'introduction de l'euro numérique si les mesures d'accompagnement sont correctement conçues. En effet, la CBDC pourrait contribuer à générer des conditions plus homogènes entre les banques des pays de la zone euro, en permettant l'absorption de grandes quantités de réserves excédentaires inutilisées (et onéreuses pour les banques) sans pour autant pénaliser les activités de crédit. Cela est important, étant donné qu'au sein de la zone euro l'excès de liquidité a presque doublé en 2020 et qu'il est susceptible de continuer à augmenter, sous l'effet des politiques monétaires non conventionnelles et des autres facteurs liés à la crise. Le taux d'intérêt négatif sur la facilité de dépôt signifie que ces réserves excédentaires représentent un coût annuel pour les banques de plus de 13 milliards d'euros. L'introduction d'un euro numérique pourrait diminuer cette charge, favorisant la profitabilité bancaire et donc l'octroi du crédit à l'économie réelle, contribuant ainsi à la relance de la production et au retour de l'inflation vers son niveau cible.

1. Introduction

The COVID-19 pandemic accelerated the process of digitalization, particularly for retail digital payments. As public concerns arose about virus transmission through paying with cash, consumers in many countries stepped up their use of contactless cards and other forms of digital payments, also in relation to expanding e-commerce activities (BIS, 2020; Auer et al., 2020). This shift has revived the debate on access to different means of payment, and on the need for resilience against a broad range of threats (Panetta, 2020). Recent scandals cast doubts on the opportunity of relying exclusively on private initiatives in this field, leading to renewed interest in central bank payment infrastructures, including general-purpose central bank digital currencies (CBDCs).

However, the costs and benefits of retail CBDCs need to be analyzed carefully. Allowing private individuals and non-banking institutions to directly access central bank balance sheets could seriously destabilize the current two-tier banking system. If central banks allowed private individuals and firms to exchange substantial parts of their bank deposits for retail CBDCs, this might facilitate bank runs. Moreover, commercial banks could be deprived of an important source of cheap funding, causing them to reduce their lending and shrink their balance sheets, which would have negative repercussions on economic activity and output unless the central bank itself takes on their role.[1] Such an outcome would run counter to monetary policy since the Great Financial Crisis, which has consistently aimed to encourage banks' credit provision to the real sector.

Nonetheless, the spillover effects of retail CBDC issuance on bank intermediation remains an open issue. A stream of literature on CBDCs does not believe that this should represent an insurmountable obstacle to implementation. Banks could find alternative funding sources on the market, without significant effects on credit granted to the real economy.[2] Otherwise, governments or central banks could provide the necessary funding to banks, if and when needed, without negative macroeconomic consequences.[3] Still, the central bank could adopt direct or indirect methods to manage the volume

[1] Several policy-makers have expressed their concern in this sense. See Mersch (2020), Carstens (2019) and Jordan (2019), among others. The recent *ECB Report on a digital euro* remarks that "The Eurosystem would design the digital euro in such a way as to avoid possible undesirable implications for the fulfilment of its mandate, for the financial industry and for the broader economy [...] thereby limiting any adverse effects on monetary policy and financial stability, and on the provision of services by the banking sector, as well as mitigating possible risks". More specifically, "[t]he digital euro should be an attractive means of payment, but should be designed so as to avoid its use as a form of investment and the associated risk of large shifts from private money (for example bank deposits) to digital euro" (ECB, 2020). BIS (2020b) also emphasizes that "a central bank should not compromise monetary or financial stability by issuing a CBDC".

[2] See for instance Sveriges Riksbank (2017) and Engert-Fung (2017). This argument is linked to the narrow banking literature (from the "Chicago Plan" in the Thirties, through the Tobin [1985, 1987] proposals to suppress deposit insurance, to the recent *Vollgeld* proposal that failed to pass a referendum in Switzerland), whose theoretical foundations can be found in the works of Modigliani-Miller (1958) and Barro (1974). Among policy-makers, BcL Governor Gaston Reinesch has also advocated the introduction of an account-based CBDC *ante litteram* in recent years: namely, allowing private individuals to open current accounts at the central bank, similar to the "deposited currency accounts" proposal of Tobin (1985, 1987), as reported by Reinesch (2021).

[3] Brunnermeier-Niepelt (2019), Sveriges Riksbank (2018) and Barrdear-Kumhof (2016).

of CBDC, avoiding excessive deposit losses that could undermine commercial banks' funding and lending.[4]

The last avenue seems particularly promising. Following this approach, the first objective of this study is to develop a realistic and comprehensive theoretical framework allowing us to explore the impact of introducing a CBDC on banks. We will see that, in the euro area, this task is complicated by the large heterogeneity across bank balance sheets. The results of the analysis are then used to clarify *i)* the order of magnitude that retail CBDC issuance could assume before threatening bank lending at an aggregate level, and *ii)* which accompanying measures could preserve the bank lending channel and avoid disruptions to financial stability.

Regarding point *i)*, Fegatelli (2019) and Bindseil (2020) have already described how a central bank could manage the volume of CBDC demanded by the public without imposing a limit. Since the attractiveness of the CBDC as an asset would critically depend on the difference between its all-in remuneration and the average rate paid by commercial bank deposits, the central bank could fix the CBDC rate or fees to an appropriate level, roughly matching the desired demand. This could involve a single variable fee on CBDC deposits or a two-tier interest rate system. In this study, we compare the two approaches and illustrate how other monetary policy tools, such as reserve requirements, could also serve to manage liquidity flows between CBDC and bank deposits.

Setting up suitable mechanisms to steer the volume of CBDC in circulation is important if the central bank wants to ensure consistency with the current monetary policy stance. For example, CBDC issuance should not trigger the absorption of more excess reserves than those deemed unnecessary for the effectiveness of (unconventional) monetary policy. On the other hand, our analysis shows that a banking system with large amounts of negatively remunerated excess reserves presumably represents the best scenario to issue a CBDC, since retail deposits lost to CBDC will mostly reduce excess reserves receiving a negative rate. A digital euro could then be configured as an additional tool for absorbing large amounts of idle and expensive excess reserves without penalizing bank lending. This is important as euro area excess liquidity increased by 99.2% during 2020, reaching the unprecedented record of 3.3 trillion euro at year-end, with an implicit cost exceeding 13 billion euro per year for the banking sector. Thus, a digital euro could improve bank profitability while generating more homogeneous conditions across banks and countries of the monetary union.

At present, Eurosystem projections anticipate that current economic weakness will persist for some time, and forward guidance by the ECB Governing Council suggests that monetary policy will remain accommodative until the medium-term inflation outlook improves. In this context, a conservative back-of-the-envelope calculation suggests that it might be plausible to issue very large CBDC amounts – slightly more than one trillion euro, at least – without negative effects for bank lending and profitability on aggregate. Indeed, if properly designed, even a digital euro with limited issuance could

[4] Bindseil (2020), Fegatelli (2019), Kumhof and Noone (2018), Meaning et al. (2018). Accordingly, ECB (2020) notes that "the central bank might mitigate potential effects on the banking sector, financial stability and the transmission of monetary policy by remunerating digital euro holdings at a variable rate over time, possibly using a tiered remuneration system, or by limiting the quantity of digital euro that users can hold and/or transact".

remarkably improve profitability among euro area banks with excess liquidity, a large deposit base and technical capacity to process instant payments on the front-end. To understand how this would be possible, let's consider that already at the end of 2019 (i.e., before the start of the new pandemic programs), the size of the Eurosystem consolidated balance sheet was greater than 4.6 trillion euro. On the liability side, nearly 1.7 trillion euro – almost 36% of the total – was represented by banks' excess liquidity, i.e., bank reserves exceeding the minimum requirements plus Deposit Facility holdings. Until September 2019, this excess liquidity was subject to a negative rate of -0.4%, representing an implicit tax of more than 6.7 billion euro per year paid by banks holding a cash surplus at the central bank. Despite the introduction of a two-tier system exempting part of excess liquidity holdings from negative interest,[5] excess liquidity still represents a serious burden in terms of profitability for those banks, like any asset bearing a negative return, year after year.

Regarding the measures that could preserve the bank lending channel (point *(ii)* above), the current volume of excess reserves is rather heterogeneous across different types of banking institutions and different euro area countries. This heterogeneity implies that even a limited or *controlled* CBDC issuance might trigger various effects on bank balance sheets and lending, depending on bank business models and jurisdictions. In particular, problems might arise for illiquid banks that depend heavily on retail deposits for funding. CBDC issuance would then create stress in the weakest parts of the euro area banking system, with all the related implications for systemic risk on aggregate. This study adapts the theoretical framework in Dutkowsky and VanHoose (2017, 2018a, 2018b and 2020) to explain why banks in some euro area countries accumulated vast excess reserves, while banks in other countries did not. This analysis then serves to identify monetary policy measures that could mitigate the impact of CBDC on weaker institutions which have limited excess liquidity and rely mainly on deposits for funding.

On a positive note, banks with large excess reserves could reduce these (along with their associated cost) by letting part of their retail deposits flow into CBDC. This would not compromise bank-customer relationships if the same banks were allowed to act as service providers on behalf of the central bank, offering dedicated access to CBDC and related administrative services to their clients. In this scenario, banks could enjoy the following four advantages.

First, CBDC user fees could contribute to bank revenues: As discussed elsewhere,[6] these fees could be based on each user's average CBDC holdings, rather than on their transaction activity. The central bank could then transfer corresponding amounts to the banks acting as CBDC agents to pay for their services. In this way, bank revenues would also be more stable through the cycle, as they would be less dependent on changes in rates and interest margins. In addition, bank competition based on

[5] In the monetary policy meeting of 15 September 2019, the ECB Governing Council decided on a further 0.1% reduction of the Deposit Facility rate to -0.5%. The Governing Council also established a two-tier system for the remuneration of excess liquidity, exempting a multiple of the total value of required reserves at the institution level from the negative rate.
[6] Fegatelli (2019).

technology and innovation would be stimulated, as the quality and range of CBDC-related services would enhance banks' ability to retain customers.[7]

Second, even banks that do not act as CBDC agents could benefit if the conversion of some of their retail deposits to CBDC reduces their excess liquidity, with no impact on other sources of revenue. This balance sheet adjustment would lower the level of excess reserves along with their associated costs under a negative interest rate policy, as mentioned above. The reduction in bank leverage would also improve gross capital ratios (see Section 4.2.3. below), with positive implications for cost savings and profitability.

Third, banks acting as CBDC agents could continue to benefit from their "know your customer" skills: By maintaining the interface with clients on both sides of their balance sheet, banks could monitor their borrowers' behavior and observe the risk attitude of net savers.

Fourth, bank contributions to the deposit insurance guarantee system could decline substantially as they are related to the volume of deposits. Moreover, the introduction of a CBDC may offer a "cheap" alternative to a fully-fledged European Deposit Insurance System (EDIS), allowing banks to save several billion euro.[8]

In this scenario, many commercial banks could complete the transition from traditional "full" financial intermediaries, taking own risks on both sides of their balance sheet, to digital banks with a richer and more diversified portfolio of advisory and agent activities, mainly (but not exclusively) focusing on banking services.[9] This conversion would follow the trend already started in the aftermath of the Lehman crisis, reflecting several factors including the low interest rate environment, Basel III regulation, unconventional monetary policies and financial digitalization.

For the central bank, issuing a CBDC biting mostly on unprofitable bank assets such as excess reserves would imply that its balance sheet might increase only marginally. A new type of liability (the digital euro) would mostly replace other pre-existing liabilities (bank reserves exceeding the minimum requirement and DF holdings), at a lower cost[10] and without necessarily inflating the Eurosystem balance sheet. This is an important difference compared to many CBDC schemes in the previous literature. The more limited increase in the monetary base means that the central bank would need to allocate fewer new funds on the asset side of its balance sheet.[11] Moreover, by guaranteeing bank funding against a partial relocation of retail deposits to CBDC, the central bank would ensure that

[7] Banks would need to update and modernize their systems in order to process instant payments from back- to front-end, if they do not want to lose those customers interested in CBDC.

[8] Fegatelli (2019) notes that a euro CBDC in the form of *universal central bank reserves* would be equivalent to fully-insured deposits, making EDIS redundant to a certain extent, and therefore allowing banks to save 43.65 billion euro of ex-ante contributions to the European Deposit Insurance Fund, an integral part of EDIS.

[9] See the report "Amazonisation is the future of European Financial Services", available on https://www.luxembourgforfinance.com/.

[10] Meaning et al. (2018) suggest keeping the CBDC remuneration below the main policy rate (i.e., the Deposit Facility rate in the euro area), to avoid interfering with monetary policy conduct.

[11] From a CBDC viewpoint, this is a positive side effect of recent purchase programs: The offsetting assets have already been "pre-loaded" in the central bank balance sheet.

money supply remains stable. By managing the volume of CBDC, the central bank could also manage the volume of excess reserves in a neutral fashion for larger monetary aggregates. Business cycle fluctuations in the money supply would be less pronounced and the money multiplier would be more stable, since a higher proportion of base money would be held outside the banking system. This would reduce an important source of procyclicality and improve financial stability, along the lines envisaged by proponents of narrow banking, and following the conclusions of recent studies noting the potential risks of excess reserves for price stability (Bassetto and Phelan, 2015).

The next section surveys recent literature on the link between unconventional monetary policies and excess reserves, including related effects on bank profitability and lending. Section 3 provides a theoretical framework to study how banks could be affected by the introduction of a retail CBDC competing with deposits. Section 4 analyzes how CBDC introduction would affect the Eurosystem balance sheet, and the implications for banks' capital and liquidity requirements. Section 5 then examines the instruments by which the central bank could manage the aggregate CBDC volume and flows between CBDC and commercial bank deposits. Section 6 provides a summary and conclusion.

2. Bank profitability, unconventional monetary policies and "excessive" excess reserves

The build-up of excess reserves is an inevitable consequence of unconventional monetary policies. Bank profitability can be adversely affected, in particular when a negative interest rate is applied to a large volume of excess reserves. However, negative rates can have beneficial effects on the economy.[12] Therefore, it may be useful to introduce an instrument that can reduce excess liquidity without affecting the monetary-policy stance in a negative interest rate environment.

2.1. Bank profitability and the debate on negative rates

The effects of low bank profitability are well documented in microeconomics. Significantly, a number of studies from Keeley (1990) to Babihuga and Spaltro (2014) show that banks with poor structural profitability can face higher funding costs and may be tempted to take on more risk.

At a macro level, preserving bank profitability is important for several reasons. First, higher profitability tends to protect financial stability (Xu et al., 2019): Profits are the first line of defense against losses from credit impairment, and retained earnings are an important source of capital, enabling banks to build strong buffers to absorb additional losses. These buffers ensure that banks can continue to provide financial services in the face of adverse developments, thereby smoothing rather than amplifying the impact of negative shocks on the real economy.

[12] Boucinha and Burlon (2020).

Second, low profitability can negatively affect the composition and quality of bank lending, causing credit misallocation. Low bank profitability is often associated with banks "evergreening" loans to "zombie" firms that may even be insolvent (Peek and Rosengren, 2005).[13] In Europe, as in Japan, credit misallocation in recent years induced undercapitalized banks to keep financing zombie firms to avoid recognizing losses on their loan portfolios (Acharya et al., 2019). This crowded out credit needed by healthier companies to grow, while hindering the deleveraging process of zombie firms in the euro periphery (Storz et al., 2017). Andrews and Petroulakis (2019) provide evidence that weak euro area banks were more likely to be connected with unprofitable firms, mostly due to bank forbearance. The same study also confirms that around one third of capital misallocation can be directly attributed to bank health, and that zombie congestion may have reduced credit supply to healthy firms, in accordance with earlier findings by Caballero et al. (2008) and Adalet McGowan et al. (2018).

Lastly, monetary policy transmission provides a third reason to preserve bank profitability. Weakly capitalized banks are constrained in their capacity to lower the interest rates charged to customers and to increase their lending volumes. This affects the bank response to accommodative interest rate policy during downturns, weakening the bank lending channel of monetary policy (de Guindos, 2019).

These problems may intensify in the presence of extremely low or even negative interest rates. For example, Banerjee and Hofmann (2018) suggest that lower rates tend to push up the share of zombie firms, even after accounting for other factors, since lower rates reduce the financial pressure on zombies to restructure or exit. In more general terms, deeply negative rates remain an unchartered territory still today. Existing data sets do not necessarily reflect possible non-linearities in bank reaction functions. As a consequence, there is considerable uncertainty regarding the distance of the current policy rates from the effective lower bound on monetary policy, e.g., in the form of the "reversal interest rate" described by Brunnermeier and Koby (2019).[14] Nonetheless, the time-varying nature of the reversal interest rate could explain (in part, at least) why the issue of bank profitability has gained further relevance recently.[15] Looking in particular at the relationship between interest rate structure and bank profitability, Borio et al. (2015) find a positive relationship between them, especially when interest rates are low. Borio and Gambacorta (2017) also find significant non-linearities, suggesting that over time and for given macroeconomic conditions, bank profitability tends to suffer from unusually low (or even negative) short-term interest rates, combined with a flat term structure. Urbschat (2018) emphasizes the role of the business model of the banks, in particular the share of overnight deposits: While some banks may benefit in the short term via reduced refinancing costs or lower loan loss provisions, many banks with high deposit ratios face lower net interest income

[13] See Kwon et al. (2015) for empirical evidence suggesting that 14 to 36% of all Japanese firms have been "zombies" at some point.
[14] The reversal interest rate is the rate at which accommodative monetary policy reverses its effect and becomes contractionary for lending. The level of this turning point may increase over time, as the negative effects on net interest income cumulate, while the positive effects on bank asset revaluation disappear.
[15] See the results of the 2019 EU-wide transparency exercise, providing detailed information for 131 banks across the EU: https://eba.europa.eu/eba-confirms-progress-banks%E2%80%99-balance-sheet-repair-points-bleak-outlook-their-profitability.

and lower credit growth rates. In the same vein, Heider et al. (2019) show that high-deposit banks suffer more from negative rates since they have difficulty passing them on to depositors, leading to an increase in their funding costs and a decline in their net worth. Thus, banks with greater reliance on deposit funding may lend less and take on more risks, as a lower net worth implies less "skin-in-the game", with possible consequences for financial stability. Buchholz et al. (2019) investigate whether lowering the deposit facility rate reduced euro area banks' incentives to hold reserves at the central bank and induced portfolio reallocation across different banks' business models and different countries during the period 2009-2014. They find that cuts in the Deposit Facility rate can cause banks to shift excess reserves into new lending, but only for banks with a more interest-sensitive business model (i.e., those more reliant on interest-bearing activities). However, these results apply mostly to well-capitalized banks in less vulnerable countries (where accommodative monetary policy is presumably less needed).

Nonetheless, the evidence of the overall effects of negative interest rates remains controversial. A much more positive view of their impact on bank profitability and lending is provided by Altavilla et al. (2018), who find that cuts in short-term interest rates or a flattening of the yield curve do not lower bank profits in the short/medium term once one accounts for the positive effects on macroeconomic and financial conditions.[16] Based on a broader data set for bank loans and explicitly considering the role of excess liquidity, Demiralp et al. (2019) reverse the conclusions of Heider et al. (2019) regarding the contractionary effects of negative interest rates on lending volumes. According to Demiralp et al., negative interest rate policy in the euro area induced high-deposit banks with excess liquidity to significantly increase their lending to households and non-financial corporations (though with higher risk-taking). In this way, the negative interest rate policy may have increased the effectiveness of the Asset Purchase Programme, by encouraging banks to convert their excess liquidity into new lending. Another recent study by Altavilla et al. (2019) suggests that the transmission mechanism of monetary policy is not impaired below the so-called "zero lower bound", but merely works differently. This study argues that the strong demand for safe and liquid assets in a negative interest rate environment allows healthy banks to pass on negative rates to their corporate depositors without experiencing a contraction in funding, thus expanding their lending more than other banks. At the same time, the costs associated with negative rates induce firms to lower their liquid assets by increasing their investment in fixed capital. Such beneficial effects on investment could explain why Altavilla et al. (2018) and Lopez et al. (2018) found that negative rates do not harm bank profitability, at least in the short term.

In summary, the debate on negative policy rates currently remains open, mostly due to uncertainties regarding the long-term impact on bank profitability and financial stability. Contrasting conclusions often reflect differences across bank business models and/or euro area countries. We will now consider the link with excess liquidity in more detail.

[16] Notice that this study does not consider the particular case of negative interest rates separately.

2.2. Excess liquidity in a negative interest rate environment

Baldo et al. (2017) and Darvas and Pichler (2018) provide two extensive reviews of excess liquidity developments in the euro area since the implementation of the Asset Purchase Programme (APP). As of September 2018, excess liquidity stood above 1.9 trillion euro, or 17% of euro area GDP. The increase in excess liquidity contributed to the central bank balance sheet reaching 41% of euro area GDP: A much smaller share than in Switzerland or Japan (both above 100%), but certainly more than in the UK or the USA. (both between 20 and 30%).[17]

Already in 2018, excess liquidity was distributed heterogeneously across euro area countries, with 80-90% concentrated in Germany, France, the Netherlands, Finland and Luxembourg. There was also a direct link between excess liquidity and Target-2 balances, since both reflect net cross-border inflows of liquidity in countries where custodians and clearing institutions sell APP securities to the Eurosystem. Comparing excess liquidity to total bank assets, in 2018 this ratio ranged from about 20% in Latvia and Finland, to 2% in Italy and 1% in Greece and Slovakia. The uneven distribution of excess liquidity was also relevant at the institutional level, reflecting several factors: Bank business models, liquidity management strategies, regulatory requirements and risk management policies, among others. For instance, investment banks and clearing institutions are more likely to accumulate excess liquidity than retail and wholesale banks. Different reasons underlie the build-up of excess liquidity by different types of institutions, such as smaller or better-capitalized banks, or banks with a higher percentage of non-performing loans. The main factor hindering the circulation of excess liquidity across the banking system is most likely capital and liquidity regulation (see Section 4.2 below), along with market segmentation linked to different country-risk premia within the eurozone.

More recently, the persistence of negative interest rates in a situation of large excess liquidity (though mitigated by the two-tier system for remunerating excess reserves) has depressed expected profitability of banks and other financial institutions, both in the short and medium-term. The revision of such expectations has pushed several banks relying on retail deposits as a funding source to pass the burden of negative rates to a larger share of their depositor base.[18] Interestingly, while the specialized media mostly focused on negative rates as a critical factor for banks' low profitability, it devoted scant attention to the role played by increasing excess liquidity. Nonetheless, negative rates are more often perceived as a burden in core euro area countries where banks have vast excess liquidity, than in peripheral euro area countries where excess reserves are low.[19]

The monetary policy literature might have contributed to this perception. So far, very few papers have focused on the dynamics of excess reserves under negative interest rates.[20] Instead, most analyses

[17] Note that in the Eurosystem as well as in other countries, the current levels of excess liquidity are considerably higher, following the implementation of the pandemic measures (see Section 4.1 below).
[18] See for instance the FT article: "Most German banks are imposing negative rates on corporate clients", November 18, 2019, and the earlier Biallo survey: https://new.biallo.de/geldanlage/ratgeber/so-vermeiden-sie-negativzinsen/ .
[19] The two-tier system for the remuneration of excess reserves seems to have accentuated this perception (see the FT article: "Italian banks rush to profit from ECB negative rates", November 12, 2019).
[20] For example, Ryan and Whelan (2019) find evidence that banks treat excess reserves as a "hot potato" to pass on to other banks or push off their balance sheets through debt securities purchases. Another strategy is

considered the build-up of excess liquidity in the euro area in the overall context of unconventional monetary policies, often as an inevitable side effect of their implementation, when not as a condition strengthening their efficacy.[21] This has made any judgement on excess liquidity directly contingent on the evaluation of the effectiveness of negative interest rates and central bank asset purchases taken together. Such an oversimplification raises two issues.

First, we should disentangle the analysis of excess liquidity from the presence of negative rates. Growth in excess liquidity may be a natural consequence of asset purchases, but it is not necessarily associated with negative rates, as we can observe in the US and other countries. This is important, because *one major factor aggravating the problem of bank profitability in the euro area is the combination of negative rates <u>and</u> large excess liquidity*.

Second, as widely discussed by Dutkowsky and VanHoose (hereinafter DVH) in relation to the US, in the post-2008 environment *it is the relative level of remuneration of excess reserves that determines the monetary policy regime in which the central bank operates*. This *relative* level of remuneration is given by the rate differential between excess reserves and the alternative(s) for investing banks' residual liquidity. The DVH model assumes that US banks see federal funds lending as the main alternative to holding excess reserves, so that the Fed can "choose" its monetary policy regime by varying the spread between the rate paid on excess reserves and the federal funds rate.

However, banks usually have at least one other alternative – other than interbank lending – to invest their excess liquidity: Government debt. Government securities can represent an attractive option for banks to "park" their unused liquidity, as far as these securities are highly liquid and can be used as top-notch collateral to generate cash if and when needed: Either via repo transactions in the interbank market or as collateral for borrowing from the central bank. Currently, the bulk of interbank lending in the euro area is in the form of secured transactions (repos and reverse repos) and unsecured lending has shrunk to a tiny share.[22] The secured segment represents about two thirds of the total money market turnover in the euro area,[23] with most contracts at one-day maturity and many others at one-week maturity. However, as explained by ECB (2019b), *"[i]n the current market environment of excess liquidity,* ***the repo market has largely become a platform for collateral exchange rather than cash management,*** *reinforced by regulatory measures under which high-quality and liquid securities are required for regulatory purposes and for covering margin calls at CCPs."* This explains why recently repo rates have often been below the Deposit Facility rate, sometimes by a substantial margin, depending on the sovereign ratings of the underlying government bonds.[24] It is significant that about

for banks to use this funding to deleverage, paying off some existing liabilities, mainly deposits from a wide range of counterparties.

[21] Apart from Darvas and Pichler (2018), see Demiralp et al. (2019) and other literature mentioned in the previous section.

[22] Most unsecured transactions, especially overnight, are outside the interbank sector, with turnover volumes declining for several years now (ECB, 2019b).

[23] ...also including foreign exchange swaps, overnight index swaps, short-term securities issuances, and the above-mentioned unsecured segment (ECB, 2019b).

[24] "Between regulatory reporting dates and without differentiating between general collateral (GC) and specific repo rates, the average transaction prices varied between -0.76% for borrowing against German government bonds and -0.48% for borrowing against Italian or Spanish sovereign bonds in the overnight, tomorrow/next and spot/next maturity buckets" (ECB, 2019b).

85% of the securities posted as collateral are government bonds, mainly issued in only six countries (Germany, Italy, France, Spain, Belgium and the Netherlands). Moreover, while government bonds from Germany and France are generally used in all locations, those from other euro area countries are mostly used in their home jurisdictions. Other recent studies (such as Schaffner et al., 2019) confirm the segmentation of the euro repo market according to the country of issue of the collateral. This segmentation appears related to the individual banks' home bias in the composition of the respective sovereign bond portfolio. As euro area banks tend to assign lower risk weights to bonds issued by their domestic government and to exploit any related sovereign spread, this home bias in bond holdings generates an incentive for banks to concentrate on the corresponding collateral segment in their repo operations.[25] Taken together, these observations clarify the functioning of the euro money market after 2008, and confirm the pivotal role of treasury rates for bank funding in the euro area.

It follows that banks' decision to deposit excess liquidity at the Eurosystem will be strongly influenced by the difference between the interest rate on excess reserves and the expected return (including possible gains from repo activity) on domestic (short-term) government debt. Note that while in the US the rates on T-Bills and federal funds tend to align under "normal" conditions[26] (see Charts A1a-b in the Appendix) – which most likely explains why DVH do not consider T-Bills as a separate alternative – in the euro area, sovereign rates often diverge across countries already at the short end of the yield curve. As an example, let's consider the yield-to-maturity for government debt with 3-month residual life for a sample of representative euro area countries since 2017 (Table 1 and Chart 1 below).

[25] Boermans and Vermeulen (2018). Domestic government bonds account for 55% of the average European bank's sovereign portfolio and 84% of the sovereign portfolio of banks from riskier countries (Koijen et al., 2016, as reported by Schaffner et al., 2019). See also Coeuré (2019) for money market fragmentation in the euro area.

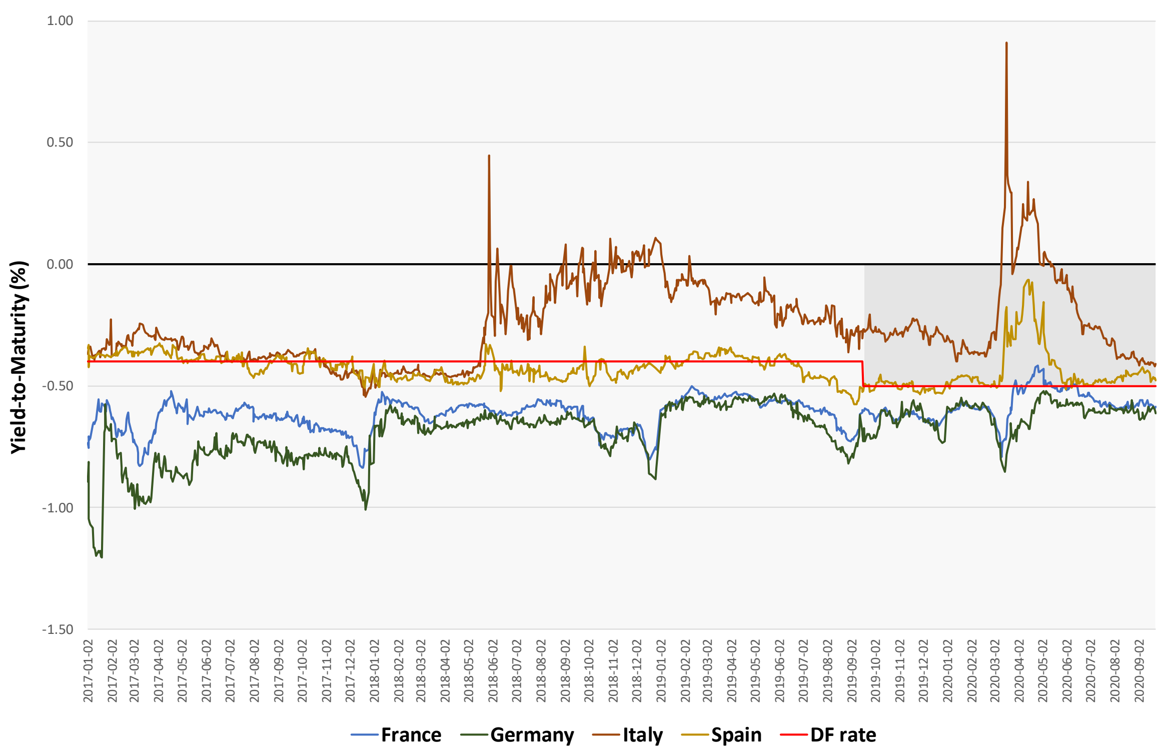
[26] Since Treasury bills and federal funds are competing investments in the US money market, they generally offer comparable yields. Notable exceptions characterize periods of money market liquidity stress, in which the federal funds rate tends to overshoot, e.g., during the Lehman crisis or (to a lesser extent) lately in 2019.

Table 1. Spread between the yield-to-maturity for government debt with 3-month residual life and the Deposit Facility rate (daily averages in percentage)

Period:	**1/2/2017-9/24/2020**	1/2/2017-9/17/2019	9/18/2019-9/24/2020
Germany	**-0.257**	-0.309	-0.119
Netherlands	**-0.226**	-0.276	-0.092
France	**-0.182**	-0.221	-0.079
Belgium	**-0.175**	-0.216	-0.068
Finland	**-0.173**	-0.218	-0.054
Austria	**-0.153**	-0.194	-0.042
Ireland	**-0.072**	-0.097	-0.005
Slovenia	**-0.010**	-0.019	0.015
Spain	**0.000**	-0.021	0.056
Portugal	**0.056**	0.057	0.054
Italy	**0.180**	0.140	0.287

Note: On 9/18/2019 the DFR moved from -0.4 to -0.5%.
Source: ECB Statistical Data Warehouse.

Chart 1. Yield-to-maturity for government debt securities with 3-month residual life in the four largest euro area economies and the rate applied to excess reserves in the Eurosystem



Note: The dark-grey shadowed area delimits the range of excess reserves' remuneration after 9/17/2019.
Source: ECB Statistical Data Warehouse.

The joint observation of Table 1 and Chart 1 above reveals quite different patterns across euro area countries. Let's take for instance Germany and Italy, the two countries at the top and at the bottom, respectively, of the list in Table 1. Since January 2017 at least, the 3-month yield-to-maturity for German debt has always remained significantly *below* the Deposit Facility rate, even if this spread has reduced by almost two thirds (or 19 basis points) on average after the introduction of the two-tier system for excess reserves remuneration in September 2019. On the other hand, the same spread for Italian debt has averaged +18 basis points throughout the entire period, and it has been associated with much higher volatility (the spread was slightly negative between the end of October 2017 and mid-May 2018, and showed two important peaks afterwards during crises). Other countries lie between these two extremes, to different extents. Evidently, the position of each country in Table 1 is strictly related to its credit rating. Charts A2a-f in the Appendix compare the short-term yield curves for selected euro area countries at different dates after the introduction of the two-tier remuneration system. These charts clearly show that the short-term yield curves of euro area core countries with higher ratings have always remained relatively stable *below* the Deposit Facility rate threshold, even at the peak of the pandemic crisis. On the contrary, the short-term yield curves of euro area peripheral countries with lower ratings have occasionally shifted entirely *above* the range of excess reserves remuneration in crisis periods.

This implies that the relative level of remuneration of excess reserves differs across euro area countries: Ceteris paribus*, it tends to be higher in countries with higher sovereign ratings.*[27] In turn, this can largely explain the heterogeneous distribution of excess liquidity across euro area member states: Unsurprisingly, those countries with the most negative spreads in Table 1 are also those in which excess reserves concentrate.[28] The next section provides a theoretical framework to justify this. It then explains how a large-scale CBDC would fit into this picture, and under which conditions its introduction could improve bank profitability without interfering with the Eurosystem monetary policy stance.

3. Modeling the impact of CBDC issuance

The approach of Dutkowsky and VanHoose (2017, 2018a, 2018b and 2020) formally investigates US commercial bank behavior in response to incentives arising from the Federal Reserve's policy stance. Their framework emphasizes that banks can operate within one of three distinct regimes, depending on the spread between the federal funds rate and the interest rate on excess reserves. The three regimes have different implications for how banks decide to invest their liquidity: *i)* banks can choose to hold zero excess reserves while investing only in wholesale loans to financial firms and

[27] Following the DVH approach, a major implication is that the ECB operates simultaneously in (at least) two different monetary policy regimes, depending on the sovereign yield of a country and the sign of its differential with the Deposit Facility rate (see next section).

[28] See earlier in this section. A relevant absence in Table 1 is Luxembourg, due to its very limited volume of short-term government debt: The first ever issue of Luxembourg Treasury Certificates (with 6-month maturity) occurred in June 2020, and it was for a total of 350 million euro only.

other banks; *ii)* banks can hold positive quantities of excess reserves and zero wholesale loans; *iii)* banks can choose to hold both excess reserves and wholesale loans at the same time. Each regime implies qualitatively and quantitatively different responses of bank balance sheet variables and market interest rates to exogenous changes, including Fed policy moves. Dutkowsky and VanHoose (2017) provide evidence that as of October 2008, banks switched from the zero-excess-reserves regime to the zero-wholesale-loan regime. Dutkowsky and VanHoose (2018a) examine implications of this change for bank retail lending, Federal Reserve balance sheet unwinding, and the effectiveness of monetary policy. Dutkowsky and VanHoose (2018b) consider the possibility of the Fed setting different interest rates for excess reserves vis-à-vis required reserves, and analyze the implications for monetary policy objectives in relation to bank lending. Finally, Dutkowsky and VanHoose (2020) find evidence of a recent switch to the "third regime", in which banks hold both excess reserves and interbank loans, and explore the impact on bank retail lending, Fed unwinding and monetary policy effectiveness.

The starting point of our analysis is the basic framework in Dutkowsky and VanHoose (2018b and 2020), slightly modified to take account of euro area peculiarities. We use this framework to explain the heterogeneous accumulation of excess liquidity across euro area banks and countries. To evaluate the impact on bank lending from the introduction of a CBDC, we use the general equilibrium approach in Dutkowsky and VanHoose (DVH) to perform a comparative statics analysis, identifying the bank lending response to an exogenous reduction in deposit supply. After verifying that we obtain similar results to those of DVH, we assume that the central bank could extend certain unconventional monetary policy measures, such as Targeted Long-Term Refinancing Operations (TLTROs). This would provide funding to those banks that cannot deleverage by reducing their excess reserves, at a cost equivalent to that of retail deposits. Our results show that, under apposite conditions largely determined by the central bank unconventional measures, introducing a digital euro could increase profitability among banks with large amounts of retail deposits matched by excess liquidity, without penalizing bank lending at an aggregate level.

The original DVH model assumes a competitive banking system, in which the representative bank is subject to the following balance sheet constraint:[29]

$$L + F + qD + X = D \tag{1}$$

where L indicates retail loans, F is wholesale loans to financial firms, q is the required reserve ratio, D denotes bank deposits, and X is excess reserves. DVH assume that L is given by the retail loan demand, defined as $L = \bar{L} - \theta r_L$, where $\bar{L}$ is an exogenous component, θ is a positive parameter, and r_L is the (positive) bank lending rate. Moreover, the original DVH model assumes that D

[29] For the sake of clarity, we follow the notation in DVH (2018b, 2020) as far as possible.

corresponds to the public's supply of deposits, defined as $D = \overline{D} + \varepsilon r_D$, where $\overline{D}$ is an exogenous component, ε is a positive parameter, and r_D is the bank deposit rate.

In our euro-adjusted framework, we borrow eq. (1) from DVH, but we decompose and/or redefine some terms, based on the discussion in the previous section. Deviating from DVH, F now includes not only wholesale loans to financial firms (or, more generically, short-term interbank lending, I), but also short-term domestic government debt (G): $F = I + G$. Moreover, D now includes not only bank deposits, that we re-denote as B, but also central bank borrowing, C, as an additional source of funding: $D = B + C$. Therefore, q indicates the share of required reserves in proportion to the overall funding: $q = q_R(B/D)$, where q_R is the required reserve ratio. Furthermore, the public's supply of deposits is redefined as $B = \overline{D} + \varepsilon r_B$, with r_B denoting the market deposit rate.

The bank's profit function remains as in DVH:

$$\pi = r_L L + r_F F + r_Q q D + r_X X - r_D D - (\alpha/2)L^2 - (\nu/2)F^2 - (\phi/2)X^2 - (\delta/2)D^2 \tag{2a}$$

where r_L is the loan rate defined as above, r_Q is the rate on required reserves (currently equal to zero in the euro area), while α, ν, φ and δ are nonnegative resource cost parameters, also including loan collateral costs and other regulatory costs associated with the corresponding balance sheet components.

The definitions of variables r_F, r_X and r_D also deviate from the original DVH model. First, because of our definition of F above, r_F can be derived as the weighted average of the short-term interbank lending rate, r_I, and the short-term domestic sovereign rate, r_G:

$$r_F = \frac{I}{F} r_I + \frac{G}{F} r_G \tag{2b}$$

As already discussed, domestic Treasury rates are a fundamental variable for banks' cash management in the euro area. Besides excess reserves, banks invest their cash surpluses mostly in short-term domestic government debt, since these securities can be used as "good" collateral either for funding (when banks need liquidity) or for generating extra profits (when such securities are requested as repo "specials", for example).[30] This justifies the straightforward replacement of F with

[30] The repo market is the only financial market in which, historically, a negative rate of return has not been unusual (see www.icmagroup.org). In the euro area, international central securities depositories such as Clearstream and Euroclear have specialized in repo and collateral management services (Fegatelli, 2010).

G, and r_F with the short-term domestic sovereign rate, r_G, in eq. (2a) above ($r_F \cong r_G$, given that $F \cong G$).

Second, the original DVH model assumes that excess reserves, X, are remunerated at a fixed rate, r_X. However, the Eurosystem currently applies a two-tier system, with a first tier – up to a multiple of the required reserves – remunerated at 0%, and the remaining second tier remunerated at the lower of zero and the Deposit Facility rate. This means that in eq. (2a) we should define r_X as

$$r_X = r_{DF}\left(\frac{X-X_1}{X}\right) \equiv r_{DF}\left(1-\frac{X_1}{X}\right) \tag{2c}$$

where $X_1 = min[X;\ m(q_R D)]$ is the amount of excess liquidity holdings that are exempted from the negative Deposit Facility rate, r_{DF}, with m equal to the required reserve volume parameter, while X, q_R and D are as defined above. In turn, this implies that, for any given amount of excess reserves, $\bar{X}$, the related interest rate is constrained as follows: $r_{DF} \leq r_{\bar{X}} \leq 0$, with $r_{\bar{X}}$ depending on the volume of (sight and short-term) deposits, $\frac{\partial r_{\bar{X}}}{\partial D} \geq 0$.

Third, for simplicity, we assume that when excess reserves are positive, the volume of central bank borrowings, C, is negligible, so that $D \cong B$, r_D approximates the rate on bank deposits ($r_D \cong r_B$), while q approximates the required reserve ratio: $q \cong q_R$. This assumption is based on the observation that, under normal circumstances, a bank does not have any incentive to stretch its balance sheet by simultaneously borrowing from and lending to the central bank at a loss.[31] However, in our framework the overall funding rate, r_D, might differ somewhat from the deposit rate, r_B, if a bank borrows significantly from the central bank at the rate r_C:

$$r_D = \frac{B}{D} r_B + \frac{C}{D} r_C \tag{2d}$$

Moreover, in our case δ, the resource cost parameter for the overall funding, is a weighted average of β and γ, the resource cost parameters for deposits and central bank borrowing, respectively:

[31] ...unless because of balance sheet dressing reasons, related to binding liquidity regulation (see later in Section 4.2.). It is noteworthy that under the current exceptional circumstances linked to the pandemic, the Eurosystem is providing long-term liquidity to banks at an interest rate level up to 50 basis points *below* the Deposit Facility rate (see the ECB press release "ECB recalibrates targeted lending operations to further support real economy", April 30, 2020). In principle, this may provide an incentive to redeposit part of these funds at the central bank, especially to banks located in countries whose domestic sovereign yields lie below the Deposit Facility rate. The outstanding increase in the amount of excess reserves during 2020 seems to confirm such view (although other crisis-related factors have also contributed to this rise).

$$\delta = \frac{B}{D}\beta + \frac{C}{D}\gamma \tag{2e}$$

At this stage, our modifications to the original DVH framework do not require any significant change to the resolution method, nor to the analytical solutions found by DVH. The first-order conditions for profit maximization are the same:

$$r_L - \alpha L - \lambda = 0 \tag{3a}$$

$$r_X - \phi X - \lambda \leq 0 \tag{3b}$$

$$r_G - \nu G - \lambda \leq 0 \tag{3c}$$

$$r_Q q - r_D - \delta D + (1 - q)\lambda = 0 \tag{3d}$$

where λ is the Lagrange multiplier or the shadow marginal profit of increasing D, and the remaining notation is the same as for above.

Following the DVH approach, we can now analyze why excess liquidity is distributed heterogeneously across different euro area banks and countries. Similar to DVH (2018b), we consider two alternatives: One in which a bank invests its excess liquidity only in central bank holdings, and one in which it invests its excess liquidity only in short-term domestic government debt.[32] In both cases, we assume *a priori* that the bank's preference for investing its liquidity surplus at negative rates, rather than deleveraging, reflects a desire to preserve its customer relationships with depositors, in line with expectations of interest rate normalization in the future.[33]

[32] A third scenario in which the bank holds positive quantities of excess reserves *and* domestic government debt simultaneously (cf. DVH, 2020) is irrelevant here, since the compounded effects on bank lending would derive from the analysis of the previous two cases.

[33] In addition to the argument of customer retention, other reasons include those of Altavilla et al. (2018, 2019) and Lopez et al. (2018) regarding the increase of banks' non-interest income, as well as the favorable treatment of central bank reserves to satisfy the regulatory liquidity ratios (see Section 4 below). We take this particular bank behavior as exogenous to our framework, in order to keep the model tractable in the context of a single-period setup designed to analyze banks' reaction to CBDC issuance. A more exhaustive treatment would presumably require an intertemporal approach including non-linear adjustment costs for certain bank

Moreover, in both cases we model the introduction of a CBDC as a negative shock affecting $\overline{D}$, the exogenous component of deposit supply, B (see earlier in this section). As observed by DVH (2018b), a variation in $\overline{D}$ can arise "from a change in any factor that exogenously affects the public's deposit supply [...], given an assumption that any change in the monetary base is willingly accepted (or released) by the public as an increase (or decrease) in deposit supply" (p. 18). Note that this statement perfectly fits our case of a decrease in deposit supply due to the crowding-out effect of CBDC issuance.

3.1. Case #1: Banks with adequate excess reserves

The first regime consists of a corner solution for short-term domestic government debt ($F \cong G = 0$), such that (3c) entails the inequality $r_G \leq \lambda$, while (1), (3a), (3b), and (3d) hold with equality.[34] As in DVH, it is easy to derive the following condition characterizing the excess reserves regime:

$$(r_G - r_X) \leq (\phi)(-\tfrac{1}{\alpha\delta})\{[\alpha(1-q)^2 + \delta]r_G + \alpha q(1-q)r_Q - \alpha(1-q)r_D - \delta r_L\} \tag{4a}$$

Once again, we can follow DVH in assuming that the cost resource ϕ is reasonably close to zero. This implies that the condition governing a switch to the excess reserves regime is the average rate of short-term government securities falling below the rate applied to excess reserves, r_X, even if by very few basis points. Since r_X cannot be lower than the Deposit Facility rate, r_{DF}, and based on our previous discussion in Section 2.2. (cf. Table 1 and Chart 1), we can observe that the condition:

$$(r_G - r_{DF}) < 0 \tag{4b}$$

is actually verified in those euro area countries where the banking system deposits a significant volume of excess liquidity with the central bank, e.g., Germany, the Netherlands and France.

balance sheet items, as in Elyasiani et al. (1995). While such an approach might permit, in principle, to derive analytic solutions for positive balance sheet quantities of excess reserves and government debt holdings under a negative interest rate regime, its implementation would not be trivial and it would stretch the analysis far beyond the scope of this study.

[34] In practice, banks may hold a minimum amount of short-term government debt for regulatory or precautionary reasons. However, this should not qualitatively affect results, so that we can maintain that $G = 0$. Alternatively, we could assume that those assets are covered by other sources of *stable* funding (liabilities) not included in our model, e.g. own capital.

The comparative statics results provided by DVH for an exogenous decline in bank deposits also apply in our framework. Thus, under the previous assumption that the cost resource ϕ remains close to zero, the effect on the volume of retail loans is virtually nil, as

$$\frac{\partial L_X}{\partial \overline{D}} = \frac{\phi\theta(1-q)}{(1+\alpha\theta)(1+\delta\varepsilon)+(\phi)[(\varepsilon)(1+\alpha\theta)(1-q)^2+(\theta)(1+\delta\varepsilon)]}$$

This result follows intuitively from the simplified version of the balance sheet eq. (1) under an excess-reserves regime: $L + X = D(1-q)$. Since the market loan rate is positive by definition in profit function (2a), while the excess reserves rate is negative or equal to zero ($r_{DF} \leq r_{\bar{X}} \leq 0$), this implies that banks react to a decline in their deposit volume by reducing excess reserves rather than retail loans, in an amount equal to $\Delta D(1-q)$, where Δ is the percentage of deposits lost: $0 \leq \Delta \leq \min\left(\frac{X}{D}; 1\right)$.

The effects on bank profitability are obvious. Following the introduction of CBDC, we can re-write the bank's profit function, eq. (2a), as follows:

$$\pi_1 = r_L L + r_F F + r_Q qD(1-\Delta) + r_X[X - \Delta D(1-q)] - r_D D(1-\Delta) - (\alpha/2)L^2 - (\nu/2)F^2 - (\phi/2)[X - \Delta D(1-q)]^2 - (\delta/2)[D(1-\Delta)]^2 \tag{5a}$$

Based on previous assumptions, this simplifies to:

$$\pi_1 = r_L L + r_X[X - \Delta D(1-q)] - r_D D(1-\Delta) - (\alpha/2)L^2 - (\delta/2)[D(1-\Delta)]^2 \tag{5b}$$

It is straightforward to verify that bank profits increase with the share of deposits shifting into CBDC:

$${}_{\Delta}\pi_1' = \frac{\partial \pi_1}{\partial \Delta} = -r_X D(1-q) + r_D D + \delta D^2(1-\Delta) > 0 \tag{6}$$

This outcome is not only affected by the interest rate paid by the bank on excess reserves and retail deposits, but also by the resource cost of deposits, δ. The positive effect on bank profitability is amplified by the level of deposits matched by excess reserves:

$$\frac{\partial\, {}_{\Delta}\pi_1'}{\partial D} = -r_X(1-q) + r_D + 2\delta D(1-\Delta) > 0 \tag{7}$$

Thus, this simple extension of the DVH model formally confirms the intuitive result that, in a negative interest rate regime, banks with adequate excess reserves might see a significant increase of their profits after the introduction of CBDC. As explained in Fegatelli (2019), banks offering CBDC access to their customers could also benefit from an additional source of profits linked to their remuneration as CBDC service providers. In this way, those banks could entirely preserve their customer relationships, thus maintaining a complete view of client activities and related risks on both sides of their balance sheets.

3.2. Case #2: Banks without excess reserves

The second regime consists of a corner solution for excess reserves ($X = 0$), so that (3b) entails the inequality $r_X \leq \lambda$, while (1), (3a), (3c), and (3d) hold with equality. Following the same procedure as before, when we substitute the solution for λ into the inequality, we can obtain the following condition characterizing the $X = 0$ regime:

$$(r_G - r_X) \geq (\nu)(\frac{1}{\alpha\delta})\{[\alpha(1-q)^2 + \delta]r_X + \alpha q(1-q)r_Q - \alpha(1-q)r_D - \delta r_L\} \tag{8a}$$

Again, following DVH in assuming that the resource cost parameter, ν, is reasonably close to zero,[35] we derive the condition governing the switch to a zero excess reserves regime as the rate of short-term government securities exceeding the average rate applied to excess reserves, r_X:

$$(r_G - r_X) > 0 \tag{8b}$$

[35] In reality, managing a portfolio of government securities should be costlier than managing reserves at the central bank, from an operational point of view, so that $\nu > \phi$. However, this difference should remain negligible in relative terms, as proved by the calibration exercise of DVH (2017).

It is noteworthy that the ECB Governing Council's decision to introduce a two-tier system for reserves remuneration in September 2019 radically changed this condition from an operational point of view, especially for banks in jurisdictions where the average cost of holding domestic short-term government debt is lower than the Deposit Facility rate. Until September 2019, r_X was equal to $r_{DF} = -0.40\%$ for all banks, which explains why excess liquidity was mainly held by banks in countries with high sovereign ratings, as explained above. Since September 2019, however, r_X varies across banks and across time, because it depends on the bank-specific ratio of excess reserves to deposits at a given moment, so that: $-0.50\% \leq r_{\bar{X}} \leq 0$.

This has led to a redistribution of excess liquidity across the euro area, incentivizing banks to make full use of their negative-rate-exempt allowances even in peripheral countries.[36] In fact, as long as $r_{\bar{X}}$ approaches zero, even Greek or Italian banks may find it convenient to accumulate excess liquidity in their accounts at the central bank. Note that between November 2019 and January 2020, i.e., before the onset of the pandemic, the euro area money market was entirely in negative territory, even for lower-rated government securities (Charts A2a-b in the Appendix). The situation worsened in the following months at the peak of the crisis, when peripheral countries' spreads rose significantly also at the short-end of the yield curves (Charts A2c-d). Later in 2020, however, the Eurosystem's monetary easing measures managed to restore or even improve the pre-crisis conditions (Charts A2e-f). This leads us to conclude that, after the introduction of the two-tier reserve remuneration scheme, condition (8b) for switching to a regime of zero excess reserves applies concretely to a much smaller group of euro area banks, at least during out-of-crisis periods.

This finding is important because in our setup, an exogenous reduction of bank deposits linked to the introduction of CBDC may have largely negative effects for lending by banks with zero excess reserves. In our framework, the comparative statics analysis for retail loans confirms the results in DVH: Assuming a sufficiently small resource cost parameter for domestic government debt, ν, the direct effect on the lending variable, L, would also be very small, though negative, since

$$\frac{\partial L_G}{\partial \bar{D}} = \frac{\nu\theta(1-q)}{(1+\alpha\theta)(1+\delta\varepsilon)+(\nu)[(\varepsilon)(1+\alpha\theta)(1-q)^2+(\theta)(1+\delta\varepsilon)]}$$

However, unlike in DVH, we need to consider second-round effects from a decrease of the exogenous component of deposit supply, $\bar{D}$. In DVH, there are no second-round effects because in the zero-excess-reserves regime, banks can invest liquidity either in retail loans or in federal funds. The federal funds market is driven by the Fed via the federal funds rate, which DVH assume to be

[36] Coeuré (2019) and ECB (2019b). See also the FT article "Italian banks rush to profit from ECB negative rates", November 12, 2019 (available online at https://www.ft.com/content/ba9d1970-04a6-11ea-a984-fbbacad9e7dd).

completely exogenous, because it is under the control of the central bank as one of its main policy instruments. In our euro-adjusted version of the model, on the other hand, banks in a zero-excess-reserves regime can invest their cash either in retail loans or in domestic government debt, so the balance sheet definition in eq. (1) simplifies to:

$$L + G = D(1 - q)$$

We assume that, following a CBDC-induced decline in retail deposits, banks would try to preserve their required reserves by selling the most liquid assets in their portfolios, i.e., government debt securities, G. Since the model refers to an individual bank, its sales – taken alone – would not immediately affect the domestic sovereign rate, r_G. However, at the level of the aggregate domestic banking sector, a wave of simultaneous sales across banks might well raise domestic bond yields[37] and, therefore, also r_G. This second-round effect would have a more substantial negative impact on bank lending, since

$$\frac{\partial L_G}{\partial r_G} = \frac{-\theta(1 + \delta\varepsilon)}{(1 + \alpha\theta)(1 + \delta\varepsilon) + (\nu)[(\varepsilon)(1 + \alpha\theta)(1 - q)^2 + (\theta)(1 + \delta\varepsilon)]} < 0$$

analogously to the comparative statics result for $\partial L_F / \partial r_F$ in DVH. Based on the previous assumption that ν is sufficiently close to zero, this simplifies to

$$\frac{\partial L_G}{\partial r_G} \cong \frac{-\theta}{1 + \alpha\theta} < 0$$

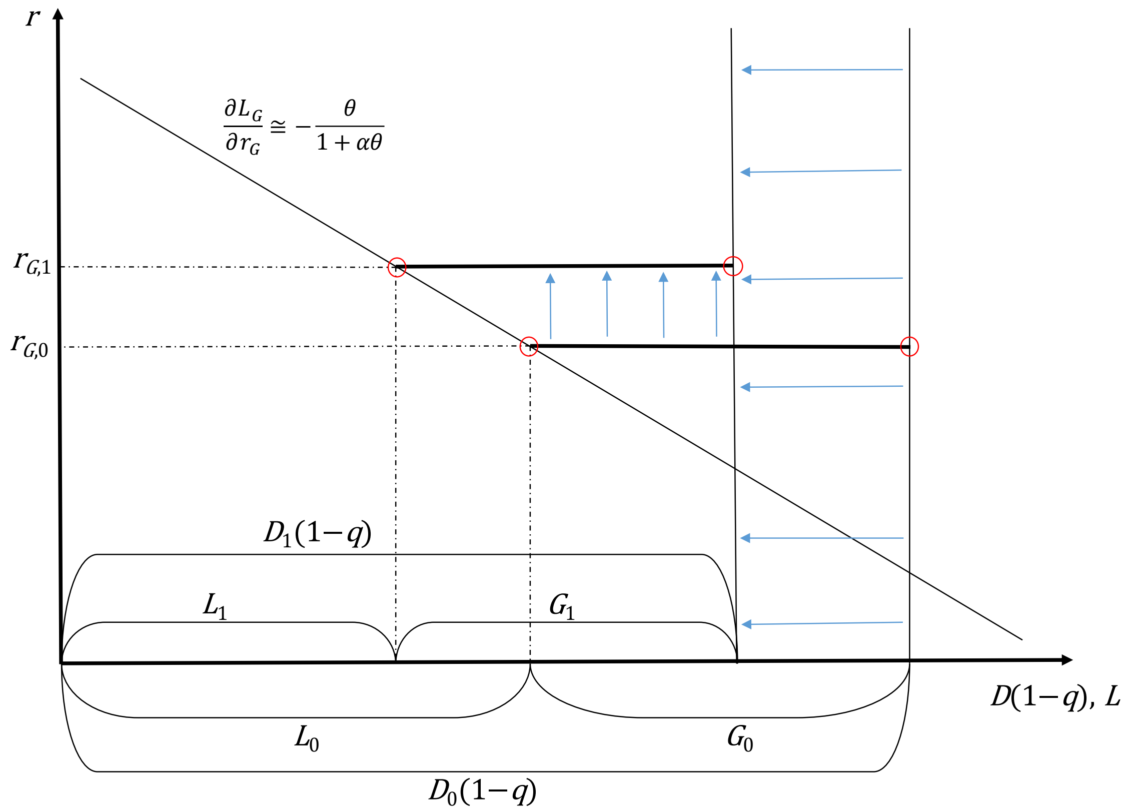
This result clearly shows that the negative effect on bank lending is independent of any funding cost parameter (as in the portfolio separation case described by DVH, 2018a).

Fig. 1 below displays this second-round effect on government yields and retail lending in a zero-excess-reserves regime. We can observe that the contraction in bank funding, due to the loss of some

[37] This would be the reverse of the hot potato effect described by Ryan and Whelan (2019). Bond spreads across euro area countries would likely increase, since sales would be concentrated in those lower rating countries where the banking sector – on net – operates with zero excess reserves. Banks holding excess reserves would likely use them to shrink their balance sheets, as seen in the previous paragraph.

retail deposits, leads to a rise in the cost of government debt service (from $r_{G,0}$ to $r_{G,1}$), crowding out bank lending to the real sector (from L_0 to L_1).

Fig. 1. Second-round effects of a reduction of bank deposits in a regime of zero excess reserves



Assuming complete separation of monetary policy from fiscal policy, the central bank has only one option to avoid a contraction in lending by banks with zero excess reserves: Offering those banks more liquidity to replace lost retail deposits as a source of funding, *under financially equivalent conditions.*[38] In our framework, this possibility is allowed by the fact that earlier in Section 3. the overall funding (*D*) was defined as the sum of retail deposits (*B*) plus central bank borrowing (*C*): $D = B + C$. Yet, the expression "financially equivalent" underlies three particular conditions:

[38] In principle, two further options (cf. Bindseil, 2020) are that *i)* the central bank buys corporate debt issued by the banking sector, and *ii)* the central bank facilitates banks' recourse to market funding (bond issuance) by further lowering interest rates and/or by buying government debt (also to reinvest the liquidity proceeds on the asset side of its balance sheet). We discard these options here, as in the current circumstances they appear politically controversial and liable to criticisms in terms of separation between monetary policy and fiscal policy, even without considering their implications for financial stability and for bank compliance with regulatory ratios.

i. The central bank should be willing to offer all the necessary liquidity on demand and at the same (flat) cost of deposits, regardless of volumes;

ii. Given that retail deposits are a form of unsecured funding for banks, whereas central bank borrowing requires banks to post collateral, the all-in cost of funding should be equivalent across the two alternatives, meaning that the opportunity cost of holding appropriate collateral to access central bank liquidity should be taken into account in this equivalence;

iii. The implicit regulatory costs of the two options should also be considered: For example, the impact on bank liquidity and capital ratios may differ depending on regulatory treatment of deposits compared to central bank borrowing (and the related collateral) as sources of funding.

In our theoretical setup, the first condition would ensure that the overall funding, D, could remain unaffected after CBDC issuance, and that the levels of r_C, the central bank borrowing rate, and r_D, the overall funding rate (see eq. [2d] above), would remain stable as new central bank borrowing replaces lost deposits. The other two conditions would constrain γ, the quadratic resource cost parameter associated with central bank borrowing (see eq. [2e] above), in order to stabilize δ, the resource cost parameter related to overall funding, as C increases.[39]

In practice, the Eurosystem monetary policy toolkit already includes adequate instruments to satisfy these three conditions. The first condition relates to the fixed-rate full allotment (FRFA) tender procedure for monetary policy lending, which the Eurosystem has followed since 2008 to cap banks' refinancing cost, lower lending spreads and preserve interest-rate pass-through to the real sector. The second condition is linked to the enlargement of the collateral framework, which was implemented in different steps, first in conjunction with the FRFA implementation, then with the adoption of the Additional Credit Claims (ACC) framework in 2011-2012, and more recently among the measures adopted during the coronavirus pandemic.[40] By extending collateral eligibility to the non-marketable and illiquid part of bank portfolios, these measures allowed monetary policy counterparties to access additional central bank liquidity, encouraging bank lending to the real sector. Lastly, the third condition is linked to the extension of certain unconventional monetary policy measures (e.g., LTROs/TLTROs) that could help banks with limited or zero excess reserves to partially substitute retail deposits with central bank borrowing, without suffering from lower liquidity and capital ratios. The next section will focus in particular on three of these ratios: The Liquidity Coverage Ratio (LCR), the Net Stable Funding Ratio (NSF) and the Leverage Ratio (LEV). But first, we need to examine the effects of CBDC issuance on the central bank balance sheet and on monetary aggregates, based on our theoretical results and the actual data.

[39] Since central bank borrowing requires collateral, unlike deposit funding, γ should normally be much higher than β in eq. [2e]. Higher quadratic resource costs are likely to represent a major obstacle for substituting deposits with central bank borrowing as a source of funding. Empirical estimation of such cost parameters is a matter for future research.

[40] See the ECB press release "ECB announces package of temporary collateral easing measures", April 7, 2020: https://www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200407~2472a8ccda.en.html .

4. Reducing excess reserves via CBDC issuance

4.1. Impact on the central bank balance sheet and on monetary aggregates

The analysis in the previous section suggests that a banking system with large amounts of negatively remunerated excess reserves represents the best scenario to issue a CBDC, since retail deposits lost to CBDC will mostly reduce excess reserves receiving a negative rate. Thus, we could plausibly assume that in a two-tier reserve remuneration system, under *normal* circumstances, the central bank may want to issue CBDC up to a level that eliminates a big part of the excess liquidity remunerated at a negative interest rate.[41]

As of the end of 2020, excess liquidity in the Eurosystem stood at 3.344 trillion euro, an increase of +99% compared to the beginning of the year. Meanwhile, the Eurosystem balance sheet size was approaching seven trillion euro (almost +50% since year-start) and will certainly increase further, under the effect of the monetary policy measures announced on December 10, 2020.[42] Evidently, these are not normal circumstances. The 2020 ballooning of excess liquidity was not unexpected, as it was largely the result of the exceptional measures taken by the Eurosystem over the year to ease monetary and credit conditions, following the outburst of the pandemic.[43] In order to adopt a conservative approach in our back-of-the-envelope estimation of a suitable size for CBDC issuance (apt to avoid negative repercussions on monetary policy and financial stability), we need therefore to look at the period immediately preceding the recent turmoil.

As of December 31, 2019, excess liquidity in the Eurosystem stood at 1.679 trillion euro, while the amount of required reserves was 134.5 billion euro. In principle, this means that the maximum exempt amount (the "exemption allowance") was 807 billion euro, i.e., 48.1% of total excess liquidity.[44] However, at the bank level many exemption allowances remained unused, due to the uneven distribution of liquidity and the reluctance of banks to trade across different euro area jurisdictions.[45] Taking account of such unused allowances, at least 30 billion euro according to Coeuré

[41] Section 2.1 cited recent literature arguing that a certain level of excess reserves contributes to the effectiveness of negative interest rate policy (Demiralp et al., 2019; Altavilla et al., 2019).
[42] ECB press release "Monetary policy decisions", December 10, 2020: https://www.ecb.europa.eu/press/pr/date/2020/html/ecb.mp201210~8c2778b843.en.html.
[43] Lane (2020); Boucinha and Burlon (2020). Both asset purchases and liquidity operations at deeply negative rates (up to -1%, i.e., much lower than the Deposit Facility rate) contributed to increment the volume of excess reserves. In addition, other crisis-related exogenous factors were at work: Forced savings linked to the lockdown measures, coupled with precautionary savings induced by higher uncertainty and risk-aversion, jointly fed a further increase in the public supply of deposits (Dossche and Zlatanos, 2020). All this led to a rise of nearly 10 billion euro in required reserves during 2020. Assuming that a very large majority of these new required reserves were related to deposits and other bank liabilities with less than 2-year maturity, this corresponds to an overall deposit supply increase approaching one trillion euro.
[44] Each bank is allocated an exemption allowance equal to a given multiple of its reserve requirement. The Governing Council set the initial multiplier at six, and the initial remuneration on exemption allowances at 0%. See the press release "ECB introduces two-tier system for remunerating excess liquidity holdings", September 12, 2019.
[45] Coeuré (2019). See again Section 2.2.

(2019), the amount of excess liquidity remunerated at a negative interest rate could be roughly estimated as nearly 902 billion euro (see Table 2 below).

Table 2. Estimated amount of non-exempt excess liquidity as of 12/31/2019 (billion euro)

Liabilities to euro area credit institutions related to monetary policy operations in euro	**1 813,38**
Current accounts (covering the minimum reserve system)	1 537,67
Required reserves (average of daily positions; period: 18/12/2019 -28/01/2020)	**134,50**
Deposit facility	275,71
Total excess liquidity	**1 678,88**
Maximum amount of exemption allowances	807,00
Unused allowances	30,00
Estimated amount of non-exempt excess liquidity	**901,88**

Source: ECB Statistical Data Warehouse; Coeuré (2019).

As CBDC is a close substitute for physical cash, the extent by which it would replace banknotes and coins could be managed by the central bank, by modulating the allure of CBDC as a financial asset.[46] Given the Eurosystem neutral policy stance with regard to the different payment instruments, we assume that the CBDC would be designed to limit the shift away from cash (ECB, 2020). Nonetheless, a long-term trend towards the digitalization of payments is ongoing on a global scale, and is also linked to demographic factors.[47] The value of banknotes issued by the Eurosystem at the end of 2019 was 1.293 trillion euro. Assuming that the CBDC would be designed to attract only 10-15% of the value of banknotes, this means that the total value of the digital euro would oscillate between 1.031 and 1.096 trillion euro, while the value of outstanding banknotes would range between 1.163 and 1.099 trillion euro. These figures should reassure the public that banknotes and CBDC would enjoy the same importance and would compete on an equal footing as a central bank means of payment.

The final impact on the size of the central bank balance sheet would substantially depend on the volume of retail deposits lost by banks operating with zero excess reserves. To summarize our discussion, the CBDC would represent a new entry on the liability side of the central bank balance sheet, whose components would derive from three sources:

[46] Agur et al. (2019) analyze the trade-off between safeguarding bank intermediation and maintaining a wide variety of payment instruments. They conclude that an interest-bearing CBDC could alleviate this tradeoff as far as the CBDC interest rate could assume negative values. This parallels the conclusions of Fegatelli (2019). Supposing the central bank wishes to remain neutral across different means of payment, there is a monetary-policy-compatible interval of values for the equilibrium interest rate of CBDC versus cash. The equilibrium rate must be negative to reflect the higher transactional utility of CBDC compared to cash (see below in Section 5.1.).

[47] Khiaonarong and Humphrey (2019).

i) Physical cash ($\boldsymbol{C1}$);

ii) Retail deposits already reinvested by banks in excess reserves, and not replaced with other sources of funding ($\boldsymbol{C2}$);

iii) Retail deposits shifting to CBDC ($\boldsymbol{C3}$), and being partially replaced by banks with central bank borrowing: $\boldsymbol{C3 \cdot (1-q)}$, where q is the required reserve ratio.

The latter category of deposits, $\boldsymbol{C3}$, once converted into CBDC, would represent a transformation of inside money into outside money (Lagos, 2006) and, as such, would be the only component expanding the monetary base and the size of the central bank balance sheet (see Tables 3a-3b below).

Table 3a. The central bank balance sheet after CBDC issuance

ASSETS			**LIABILITIES**		
Lending to EA banks	624.2	$\boldsymbol{+C3 \cdot (1-q)}$	Banknotes in circulation	1,292.7	$\boldsymbol{-C1}$
Securities of EA residents	2,847.1		Liabilities to EA banks	1,813.4	$\boldsymbol{-C2 - q \cdot C3}$
Other	1,201.8		Other	1,567.1	
			CBDC		$\boldsymbol{+C1 + C2 + C3}$
Total:	**4,673.2**	$\boldsymbol{+C3 \cdot (1-q)}$	**Total:**	**4,673.2**	$\boldsymbol{+C3 \cdot (1-q)}$

*Table 3b. The central bank balance sheet after CBDC issuance (**C1**=193.9 bn €; **C2**=901.9 bn €)*

ASSETS			**LIABILITIES**		
Lending to EA banks	624.2	$+\boldsymbol{C3} \cdot (\mathbf{1} - \boldsymbol{q})$	Banknotes in circulation	1,292.7	***-193.9***
Securities of EA residents	2,847.1		Liabilities to EA banks	1,813.4	***-901.9*** $-\boldsymbol{q} \cdot \boldsymbol{C3}$
Other	1,201.8		Other	1,567.1	
			CBDC		+***1,095.8*** $+\boldsymbol{C3}$
Total:	**4,673.2**	$+\boldsymbol{C3} \cdot (\mathbf{1} - \boldsymbol{q})$	**Total:**	**4,673.2**	$+\boldsymbol{C3} \cdot (\mathbf{1} - \boldsymbol{q})$

Source: Eurosystem consolidated balance sheet data as at December 31, 2019 (EUR billions).

In spite of the possible increase in the monetary base (the monetary aggregate ***M0***), the introduction of CBDC, if implemented as illustrated above, would not affect monetary aggregates ***M1*** and ***M2***. Recall that ***M1***, the narrow definition of money, is defined by the ECB as currency in circulation plus overnight deposits.[48] In terms of the CBDC components above, the first, $\boldsymbol{C1}$, would merely convert one form of currency in circulation into another, with no impact on any monetary aggregate, not even on ***M0***. As for $\boldsymbol{C2}$ and $\boldsymbol{C3}$, they would convert overnight bank deposits into (digital) currency in circulation, leaving unchanged both ***M1*** and, most likely, also ***M2***, the sum of ***M1*** plus deposits with an agreed maturity of up to two years and deposits redeemable at notice of up to three months.

The impact on ***M3***, however, might be different. This is the broad money aggregate most relevant for monetary analysis, defined as the sum of ***M2*** plus specific marketable liabilities of the MFI[49] sector (such as repurchase agreements, money market fund shares/units and money market paper, together with debt securities issued with an original maturity of less than two years). The value of such marketable liabilities might be negatively affected by the likely decrease of the two liquidity and funding ratios, LCR and NSF (see definitions above), following the partial shift of retail deposits to CBDC. As explained in more detail in the following section, this could happen both to banks with adequate excess reserves and to those without, in spite of the possible replacement of retail deposits with central bank borrowing.

In order to avoid a lending contraction linked to a reduction in market funding, the central bank might therefore wish to further strengthen its lending to banks, so as to shield the bank lending channel from any indirect negative effects stemming from the decline in the retail deposit base. To this end, the central bank could preserve certain *ad hoc* crisis measures or even implement new

[48] ECB (2019a).
[49] Monetary Financial Institutions (*ibid.*).

monetary policy measures, aimed at counterbalancing the contractionary effect on LCR and NSF (see the next section). In addition, central banks and bank supervisors/regulators could agree some changes to the calculation of the NSF ratio, without deviating significantly from the standard Basel III framework.

4.2. Effects on banks' liquidity, funding and capital ratios

The regulatory capital effects stemming from a partial shift of retail deposits to the CBDC would basically depend on banks' availability of adequate excess reserves. Here we focus on three ratios in particular: 1) LCR, 2) NSF, and 3) LEV, the leverage ratio.[50]

4.2.1. The effects on the liquidity coverage ratio (LCR)

The Basel Framework defines the LCR as follows:

$$\frac{Stock\ of\ High\text{-}Quality\ Liquid\ Assets\ (HQLA)}{Total\ net\ cash\ outflows\ over\ the\ next\ 30\ calendar\ days} \geq 100\%$$

In general, losing retail deposits would have a negative effect on a bank's LCR, due to their favorable treatment in the calculation of the ratio. The Basel Framework allows retail demand deposit run-off as low as 3% in the denominator of the LCR (case of "stable deposits"), but it could be 10% or higher for those deposits that are not covered by a deposit insurance guarantee ("less stable deposits"). However, for Eurosystem banks using excess reserves to cover their deposit outflows, this would imply a reduction of the numerator up to 99%, since excess reserves are considered "level 1 assets", not subject to any haircut.[51] Notice that the necessary condition to avoid a negative impact on the ratio, following the partial shift of retail deposits to the CBDC, is for these banks to have an initial LCR level of 990% (at least), which is clearly unrealistic as well as undesirable from the point of view of bank profitability.[52]

Banks replacing retail deposits with central bank borrowing, on the other hand, would also see their LCR decrease, insofar as they would likely need to pledge part of their HQLA as collateral for new central bank borrowing. A binding operational requirement for including an asset in the HQLA stock is that the asset in question should be "unencumbered": i.e., "free of legal, regulatory, contractual or other restrictions on the ability of the bank to liquidate, sell, transfer, or assign the asset" (Basel

[50] See Basel Committee on Banking Supervision (2020).
[51] The remaining 1% corresponds to the percentage of required reserves, not eligible for inclusion in HQLA (Bucalossi et al., 2016).
[52] This necessary condition can be expressed as: $(a-d)/(b-c) \geq a/b$, where a is the initial stock of HQLA, d is the HQLA reduction due to the excess reserves decrease, b is the initial level of total net cash outflows, and c is the cash outflows reduction related to the loss of deposits. Since $d = D(1-r)$, where D is the amount of shifted deposits and r is the minimum reserve requirement ratio, and $c = D \cdot \rho_D$, with ρ_D, the run-off rate of deposits, assumed equal to 10% (best case scenario), it follows that $a/b \geq d/c = (1-r)/\rho_D = 0.99/0.10 = 990\%$.

Committee on Banking Supervision, 2020). This means that, also for banks without excess reserves, the LCR could decrease because the numerator drops more than the denominator.

Thus, in both cases banks could find it convenient to borrow at the central bank by pledging assets not included in the HQLA stock. Following the Eurosystem measures adopted in April 2020 to ease credit conditions, banks could then further lever the use of credit claims and other non-marketable assets as collateral for central bank borrowing. In the CBDC scenario, this would allow those banks to replenish their level of excess reserves or to use central bank borrowing as a lasting source of funding in lieu of lost retail deposits. For this to be possible, nonetheless, the whole package of collateral easing measures may need to become a permanent feature of the Eurosystem collateral framework, well beyond the duration of the coronavirus crisis and the related special measures.[53] As an alternative, central banks may want to ask bank supervisors and regulators to rediscuss the calculation and/or implementation of the LCR.[54]

4.2.2. The effects on the net stable funding ratio (NSF)

The Basel Framework defines the NSF[55] as: $\frac{Available\ amount\ of\ Stable\ Funding\ (ASF)}{Required\ amount\ of\ Stable\ Funding\ (RSF)} \geq 100\%$

As for the LCR, the preferential treatment of demand deposits implies that their loss penalizes banks: Insured retail demand deposits and term deposits with residual maturities of less than one year receive a 95% factor in the calculation of the ASF, while even uninsured deposits with the same characteristics receive no less than a 90% ASF factor. Therefore, under the current regulatory framework, the impact of deposit losses would always be negative, as the ratio would drop regardless of the level of excess reserves.

Even banks covering a deposit squeeze with their excess reserves would see a decline in the numerator of their NSF ratio without any change to the denominator, as excess reserves receive a 0% factor in the calculation of the RSF. This situation is paradoxical, since banks would clearly prefer to reduce negatively-remunerated excess reserves that impact on profitability and increase their need for funding. In other words, it seems that in this particular case the mechanical application of the NSF regulation runs against the regulator's intention, which is "to reduce the likelihood that disruptions to

[53] According to the ECB announcement of April 7, 2020, only certain haircut adjustments applied to non-marketable assets are considered permanent and, therefore, not subject to further reassessment following the evolution of the pandemic crisis.

[54] The introduction of a digital euro may affect the stability of retail deposits for commercial banks, as in crisis times large amounts of deposits would likely shift to the central bank. Accordingly, this would call for a revision of the respective outflow factors in the LCR denominator. However, it should be considered that already today retail deposits can shift from one bank to another – or to a fintech player – with a simple click, in a matter of seconds (Sveriges Riksbank, 2018). Thus, revising the outflow factors for deposits will presumably become necessary regardless of the existence of CBDCs.

[55] Recall that "'*Available stable funding*' is defined as the portion of capital and liabilities expected to be reliable over the time horizon considered by the NSFR, which extends to one year. The amount of such stable funding *required* ('Required stable funding') of a specific institution is a function of the liquidity characteristics and residual maturities of the various assets held by that institution as well as those of its off-balance sheet (OBS) exposures" (Basel Committee on Banking Supervision, 2020).

a bank's regular sources of funding will erode its liquidity position in a way that would increase the risk of its failure and potentially lead to broader systemic stress" (Basel Committee on Banking Supervision, 2020). Here, an environment of persistent excess liquidity associated with negative rates clearly reduces banks' net interest income, and therefore may raise their risk of failure, while eliminating part of this excess may *not* increase a bank's liquidity risk significantly. In addition, excess reserves could be considered as a special asset providing the most stable funding source (as they are entirely at the disposal of the owner, without any constraint), such that it can be used at any time to "neutralize" the impact on a bank's funding liquidity position from a loss of deposits.[56]

To offset a decline of their retail deposits, banks could have recourse to market funding, or they could borrow from the central bank at maturities longer than one year:[57] For example via the TLTRO operations implemented by the ECB since 2014, and revived more recently in the context of the coronavirus crisis.[58] Depending on general financial and economic conditions, the central bank might need to further extend the maturities and to renew the favorable terms currently offered for such operations. However, this alone would not be enough to avoid a negative impact on the NSF ratio of those banks losing deposits.

Any form of central bank borrowing needs to be collateralized, but all assets encumbered for one year or more receive a 100% RSF factor in the denominator of the NSF ratio. Since most categories of assets that are either sufficiently liquid (marketable) or have at least a minimum acceptable rating (not necessarily up to the HQLA level) receive an RSF factor less than 100% when they are unencumbered, this means that whenever banks use such assets as collateral for central bank borrowing, their RSF increases. Whether the final effect on the NSF ratio is negative or positive depends on the ASF increase after borrowing (i.e., the borrowed amount), which – in turn – depends on the collateral haircut applied to these assets. Bucalossi et al. (2016) show that, based on the type of collateral pledged by banks in 2014-2015, the final effect on the NSF would be positive for most banks, provided that they prioritize the use of their most illiquid or low-quality (though eligible) assets as collateral. However, in our case this positive effect might not suffice to compensate the decline in NSF ratio linked to the loss of deposits (i.e., the deposit-related 90-95% value reduction in the ASF), unless we assume that all the new funding is obtained by pledging only illiquid and/or low-quality assets that already receive a 100% RSF factor, so that the denominator of the NSF ratio remains unchanged.

One straightforward solution would be to change the asset encumbrance treatment for central bank operations: Assets encumbered for central bank liquidity operations would receive the same RSF factor as a similar unencumbered asset. This would allow a bank losing (part of) its retail deposits to restore the original ASF volume via longer-term central bank borrowing with no impact on the RSF – regardless of the choice of assets used as collateral – so as to preserve its NSF ratio in any

[56] This aspect is not taken into account by the Basel III requirements, most likely because at the time of their elaboration, the persistence of a large amount of negatively-remunerated excess reserves had not been envisaged. The literature also seems to largely neglect this topic.
[57] Any liabilities with effective residual maturities of one year or more receive a 100% ASF factor.
[58] See the ECB monetary policy decisions of March 12, April 30, and December 10, 2020, along with the related press releases.

circumstance. This approach would be consistent with the NSFR framework, in as far as *i)* the RSF factor applied to an asset used as central bank collateral is not below the RSF factor applied to the equivalent unencumbered asset, and *ii)* this treatment is only reserved to assets pledged for "exceptional" central bank liquidity operations, such as TLTROs.[59][60]

Such an environment would offer a backstop not only to preserve the NSF ratio, but also to protect and even enhance bank profitability, in particular when the cost of stable (market) funding is higher than the cost of deposit funding.[61] Importantly, banks could still pledge their excess reserves to borrow long-term from the central bank: This would be equivalent to "freezing" such reserves, so as to turn them into a source of ASF and to restore the numerator of the NSF ratio. This might be an option if banks with excess reserves have high market funding costs and no other assets to pledge with the central bank. However, even in this special case banks could marginally reduce their excess liquidity and, therefore, improve their profitability. Notice that retail demand deposits receive an ASF factor between 90% and 95%, while the collateral haircut applied to excess reserves is zero. This implies that for 100 euro of lost deposits that were entirely covered by reserves, banks could always give up between 4 and 9 euro of excess reserves,[62] which would be unnecessary for central bank borrowing.

4.2.3. The effects on the leverage ratio (LEV)

Recall that the LEV is defined as: $\frac{Capital\ Measure\ (CM)}{Exposure\ Measure\ (EM)} \geq 3\%$, where the CM is what is known as the Tier-1 capital of the Basel III risk-based capital framework, while the EM is the sum of four different types of exposures (on-balance sheet items, derivatives, securities financing transactions and off-balance sheet items).

Assuming the existence of a suitable central-bank backstop facility to replace deposit funding, the effect on the LEV from a decline in retail deposits would always be positive for any bank, regardless of its level of excess reserves. Banks covering deposit losses with reductions of their excess reserves without recourse to additional funding, would see their balance sheet shrink and their LEV increase

[59] "Exceptional" operations are defined as those "non-standard, temporary operations conducted by the central bank in order to achieve its mandate in a period of market-wide financial stress and/or exceptional macroeconomic challenges" (Basel Committee on Banking Supervision, 2020).

[60] The reserves expressed by Bucalossi et al. (2016) on such preferential treatment (i.e., competition between market funding and central bank funding, possibility of regulatory arbitrage by banks, etc.) should presumably be reconsidered as minor issues in today's digital environment characterized by much higher volatility of demand deposits and more generalized recourse to central bank funding, especially in crisis periods. Some bank supervisors may perceive this proposal as a sort of "ratios manipulation", accentuating banks' reliance on central bank funding. However, as already explained, recent technological advances make it inevitable to revise the outflow factors for deposits regardless of CBDC existence. For the NSF ratio, a higher volatility of deposits implies a reduction of the related ASF factors, i.e., a smaller numerator and, therefore, a decrease of the ratio.

[61] See Hoerova et al. (2018).

[62] We assume that the standard reserve requirement ratio of 1% applies.

correspondingly.[63] However, we have seen above that even banks with sufficient excess reserve might need or want to borrow from the central bank in their attempt to maintain the LCR and the NSF ratio at an adequate level.

Suppose that a bank wants to replace all lost deposits with new central bank borrowing, e.g., in order to keep its lending volume unchanged. This could reduce the bank's balance sheet by 1% of the lost deposits, as there would be no need to make up for the amount corresponding to the reserve requirement. Therefore, even banks without excess reserves – or unwilling to reduce their volume of excess reserves – could always marginally improve their LEV by substituting deposit funding with central bank borrowing (provided that they have adequate collateral).

Notice that this favorable effect on the capital ratio would run against the negative effects on the liquidity and funding ratios discussed above (in the absence of any further central bank intervention and regulatory changes).

4.2.4. Summary

Table 4 below offers a synopsis of the regulatory capital and liquidity effects stemming from a partial shift of banks' retail deposits into CBDC. The last column to the right indicates some corrective measures that central banks and supervisors could implement to alleviate negative effects. Importantly, the adoption of such measures would be subject to opportune policy decisions whose thorough implications go beyond the scope of the present analysis, which does not intend to offer normative prescriptions.

[63] The LEV makes no special allowance for excess reserves or for required reserves, other than allowing for an optional temporary exemption under exceptional macroeconomic circumstances and conditional on a commensurate increase of the required ratio.

Table 4. Effects on banks' compliance with Basel III liquidity and capital ratios from a partial shift of banks' retail deposits into CBDC

Ratio	Type of bank	Direct effect	Causes	Possible mitigating measures
LCR	Holding excess reserves	↓↓ / ↓	Favorable treatment of retail demand deposits; strict rules on encumbered HQLAs	– ***Favor the use of credit claims and other (non-HQLA) non-marketable assets as collateral for central bank borrowing*** – ***Maintain pandemic-related collateral easing measures as a permanent feature of Eurosystem collateral framework***
	Without excess reserves	↓		
NSF	Holding excess reserves	↓	Retail demand deposits with <1y residual maturities receive a 90-95% ASF factor: Loss of deposits reduces NSF numerator considerably	– ***Extend/renew monetary policy operations with maturities >1y (LTROs/TLTROs), possibly maintaining current favorable terms (if necessary)*** – ***Change asset encumbrance treatment for central bank operations: Assets encumbered for central bank borrowing to receive the same RSF factor as similar unencumbered assets***
	Without excess reserves	↓		
LEV	Holding excess reserves	↑↑ / ↑	Banks to cover deposit shifts with excess reserves or central bank funding, reducing their balance sheet by 1% of lost deposits (at least)	Unnecessary
	Without excess reserves	↑		

In principle, the mitigating measures listed above could stabilize the LCR and the NSF ratio to a very large extent. These measures would ensure adequate credit support to the banking sector by acting in two critical areas of monetary policy implementation: *i)* the collateral framework, and *ii)* the maturity of Eurosystem refinancing operations. In addition, adjusting the NSF regulatory treatment of bank assets used as collateral in central bank operations would also deter banks from excessive deleveraging and from reducing lending to the broader economy.

5. How to control CBDC quantities

The final part of this study presents two instruments by which the central bank could control CBDC volumes: *i)* the overall remuneration on CBDC (including interest, charges and fees), and *ii)* the reserve requirement ratio. The first instrument would combine interest payments and charges/fees to manage the attractiveness of the CBDC as a store of value. It could function as a new monetary policy tool, if we conceive CBDC as *universal central bank reserves*. The second instrument is not new at all, but it has been used for decades by central banks worldwide, albeit for different purposes and to a very different extent. In a CBDC framework, the reserve requirement ratio could be employed as a sort of "emergency brake" to offset the emergence of swift flows between commercial bank deposits and CBDC under exceptional circumstances.

5.1. Managing the CBDC remuneration

Following the approach of Fegatelli (2019), we assume that the central bank does not want to:[64]

i. Compromise the two-tier banking intermediation system underlying the bank lending channel of monetary policy transmission;

ii. Risk its financial and political independence by excessively increasing its footprint in the economy;

iii. Influence economic agents' choice among different means of payment.

Consequently, an appropriate interval of value for the CBDC nominal rate of return, R^C, is the following:

$$LB(\overline{U}_{CC}) < R^C < \min(R^B = 0\,; R) \tag{9}$$

where $LB(\overline{U}_{CC})$ indicates the lower boundary, which is a function of the expected utility of private monies (stablecoins, cryptocurrencies, etc.), foreign currencies and any other viable payment alternative that could serve for a "dollarization" or "libra-ization" of the economy. On the other side, the upper boundary is given by the lower of $R^B = 0$ (the physical cash nominal rate of return) and the key policy rate, R (the theoretical risk-free rate).[65]

[64] These assumptions adhere to the foundational principles a CBDC would need to observe in order to contribute to central bank policy objectives, as enunciated by BIS (2020b).

[65] Within this interval, the CBDC could be (slightly) more or less attractive than physical cash, depending on the differential between R^C and the implicit cost of holding cash (e.g., costs of opening and maintaining a current account, or the use of vaults), besides the gap between the non-pecuniary transactional expected

This slightly negative interest rate could be charged to CBDC holders in the form of a variable-rate deposit fee, based on the outstanding amounts held in CBDC accounts. From an economic point of view, this fee would be perfectly justified by the operational and maintenance costs borne by the central bank, either directly or indirectly (if CBDC accounts were operated by a third-party service provider). In fact, this would be broadly similar to current practice with some commercial bank deposit accounts. Only the CBDC account fees would be anchored to the main policy rate(s), within the specified interval, while the CBDC nominal interest rate would remain constant at zero (similar to cash).

In the same vein, Bindseil (2020) proposes a two-tier remuneration system for CBDC accounts, where tier 1 is always linked to a non-negative remuneration only up to a limited amount (e.g., 3,000 euro). Beyond that ceiling, tier-2 remuneration would apply, equal to the minimum between zero and a penalty (negative) rate anchored to r_{DF}, the Deposit Facility rate (e.g., $r_{DF} - 1\%$).

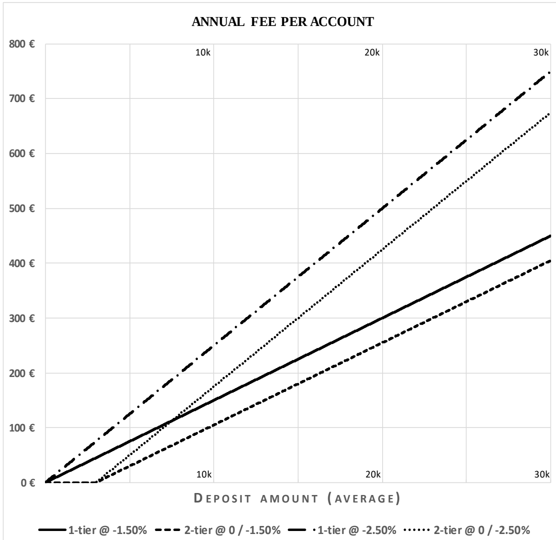
These proposals share the basic idea of incentivizing the use of CBDC as a means of payment complementary to cash, but not as a store of value (see assumption *i)* above). Table 5 and Charts 2a-2b below compare the applicable fees of the two pricing proposals for different amounts held in euro CBDC accounts and across two different penalty spreads (-1% and -2%), assuming the current level of the Deposit Facility rate (the relevant policy rate).

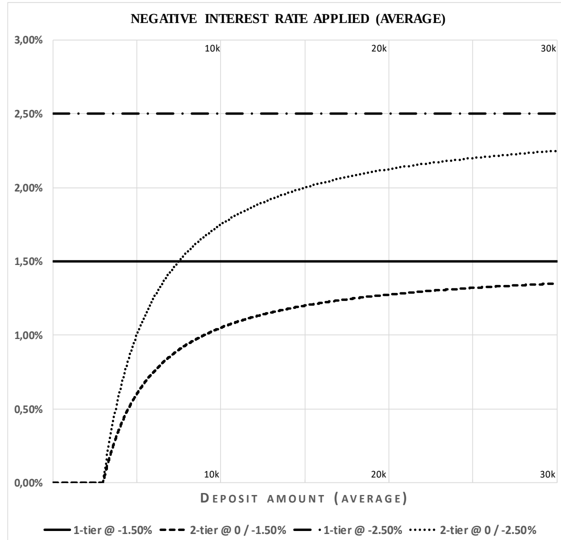
Table 5. A comparison of two CBDC pricing proposals

Possible schemes for CBDC annual fees								
Deposit amount (EUR)	CBDC rate: -1.50%				CBDC rate: -2.50%			
	Fee (one-tier)	Average rate	Fee (two-tier)	Average rate	Fee (one-tier)	Average rate	Fee (two-tier)	Average rate
1 000	15	-1,50%	0	0,00%	25	-2,50%	0	0,00%
2 000	30	-1,50%	0	0,00%	50	-2,50%	0	0,00%
3 000	45	-1,50%	0	0,00%	75	-2,50%	0	0,00%
4 000	60	-1,50%	15	-0,38%	100	-2,50%	25	-0,63%
5 000	75	-1,50%	30	-0,60%	125	-2,50%	50	-1,00%
10 000	150	-1,50%	105	-1,05%	250	-2,50%	175	-1,75%
20 000	300	-1,50%	255	-1,28%	500	-2,50%	425	-2,13%
50 000	750	-1,50%	705	-1,41%	1 250	-2,50%	1 175	-2,35%
100 000	1 500	-1,50%	1 455	-1,46%	2 500	-2,50%	2 425	-2,43%

utilities of the two media of payment. However, this relatively small differential should not significantly affect public preferences between CBDC and cash.

Charts 2a-2b. Alternative schemes for charging CBDC accounts





Assuming that the Eurosystem would wish to limit CBDC issuance to slightly more than 1 trillion digital euro (see Section 4 above), if we divide this figure by an eligible euro area population slightly above 340 million people, this would imply a CBDC deposit of around 3,000 euro per person on average (Bindseil, 2020). At this level, and assuming a single digital euro account per person, a simple one-tier fee scheme would generate an annual account fee equal to 45 euro (for $R^C = r_{DF} - 1\%$) or 75 euro (for $R^C = r_{DF} - 2\%$). This is comparable to fees charged on current accounts by many retail banks in Europe, when we include different billing items (for account maintenance, cash withdrawals, transfers, etc.).

On the other hand, a two-tier scheme exempting the first 3,000-euro tranche of CBDC deposits from any fee payment would raise the convenience of holding CBDC even above the 3,000-euro limit (see Table 5 and Charts 2a-2b). This would undermine the rationale for having a two-tier remuneration scheme in place with that threshold. In any case, different types of negative remuneration or fee schemes can be conceived to charge depositors and payment system users, as we can learn from multiform pricing strategies adopted by the banking industry.

A major point of this discussion is that controlling CBDC volumes can be eventually reduced to a Pigouvian problem: In practice, the central bank could easily increment the CBDC supply to fully satisfy users' demand at a price (CBDC fee) equal or lower than zero (in case of positive CBDC remuneration).[66] As we can infer from (9), however, such fee levels would be below the social optimum, defined in terms of long-term financial stability, monetary policy and financial inclusion

[66] The ECB Report on a digital euro seems to hint at this possibility when it suggests that "a digital euro should be […] free of charge" and that "[i]f considered to be a tool for improving the transmission of monetary policy, the digital euro should be remunerated at interest rate(s) that the central bank can modify over time" (ECB, 2020).

objectives. A substantial motivation for a negative CBDC rate of return, R^C, is to incorporate the Pigouvian tax in R^C, to prevent negative externalities: *In primis*, possible bank disintermediation undermining the process of credit allocation to the real economy, or a decline in cash usage that could eventually lead to its complete disappearance from circulation.[67]

5.2. The use of the reserve requirement tool in a CBDC framework

In a CBDC framework, reserve requirements (RR) would offer a second, more direct instrument to control CBDC flows – an "emergency brake", as we said above. In principle, a simpler alternative would be to impose some "hard" limits on the availability of the CBDC beyond a certain threshold. For example, the central bank could impose a ceiling on CBDC accounts, either by refusing the settlement of any transaction that would trigger a violation of the limit, or by rerouting the same settlement towards a commercial bank account belonging to the same user. However, such solutions would present some serious drawbacks both from an operational and from a legal point of view (if the CBDC had legal tender status, for instance); they might generate arbitrage opportunities to elude the limit, and they could even undermine public confidence in CBDC.

The use of RR in a CBDC framework, on the other hand, would focus specifically on the link between commercial bank deposits and CBDC holdings by acting on the rate differential between the two asset types. The mechanism would be analogous to the one described by the economic literature on the use of RR in emerging market economies with a flexible exchange rate.[68] In that case, RR are used as a countercyclical tool for macroeconomic stabilization to influence bank lending conditions (rates and volumes) without "overcharging" the policy rate, whose excessive variation might trigger international capital flow shifts contrary to the intended effect. Suppose, for instance, that too strong an increase in the policy rate intended to tighten conditions during an expansion would attract foreign inflows, increasing liquidity and further appreciating the domestic currency. Following the Tinbergen rule, central banks in emerging market economies may want to assign the RR ratio the task that policy rates cannot achieve because they are tied to another objective (e.g., price stability or an exchange rate target). Assuming that the required reserves remuneration lies below the market rate, an RR increase then acts as a tax on banks' interest income, leading to a rise in lending rates and to a decline in deposit rates.[69] As observed by Alper et al. (2018), the RR transmission mechanism acts through the traditional cost channel as long as central bank credit and deposits are close substitutes as alternative sources of bank funding, e.g., in the absence of frictions linked to central

[67] More precisely, ECB (2020) suggests that "a digital euro should be [...] free of charge for basic use by payers" (Requirement 2: Cash-like features). The present discussion makes it clear why this "basic use" should not include the "store of value" function: Meaning that charges and fees should *not* be applied on numbers/volumes of transactions, while they could be imposed on CBDC holdings (as a function of time and volumes). As for the argument that cash is "free of charge" in a wider sense, it could be objected that cash availability actually depends on users maintaining accounts with banks or other institutions dispensing cash and allowing for large-value payments (which are prohibited in cash beyond a certain limit), and that this is liable to bundled fees and periodic expenses. Storing cash is even more expensive and risky, as it implies the use of private safes and/or bank vaults.

[68] See for instance Cordella et al. (2014) and OECD (2018).

[69] Glocker and Towbin (2012).

bank collateral eligibility or binding liquidity/capital regulation. This being a fundamental condition for a smooth introduction of CBDC in our theoretical setup, we can now describe how similar RR measures would work in our framework, given the same nature of the problem and the same transmission mechanism.

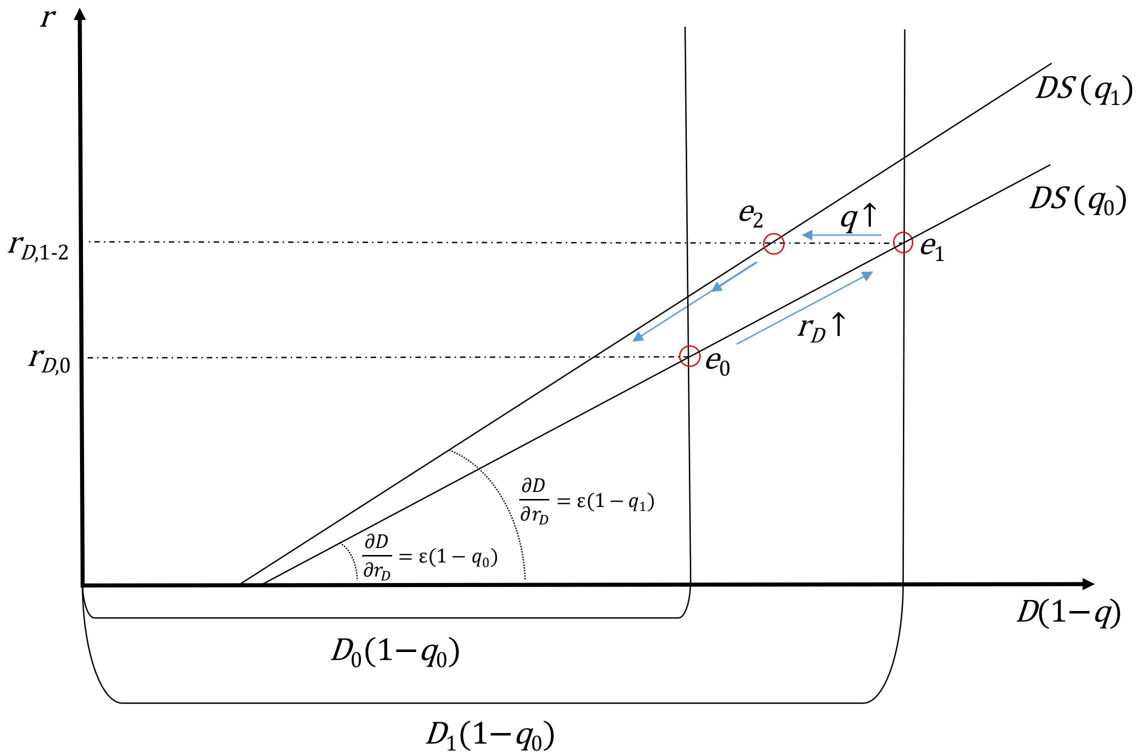
The need to use the RR as an instrument might emerge, for instance, following a *normalization* of monetary policy conditions in which the policy rate turns significantly positive. In such circumstances, if instead of following the rule in (9) the central bank kept the CBDC rate constantly anchored to the policy rate, an increasingly positive gap between the remunerations of CBDC and physical cash would arise. This might finally lead to an irreversible extinction of cash (because of its higher holding opportunity cost), violating the Eurosystem principle of neutrality between different means of payment and potentially reducing financial inclusion among the older and less educated population. On the other hand, following the rule in (9) would imply that, for positive policy rates, CBDC would become a fixed, zero-interest asset (like cash or gold): Funds from CBDC would then easily tend to switch to bank deposits or back, depending on the direction of change in the policy rate, with all the related problems for banks' liquidity management, financial stability, and the conduct of monetary policy. While in emerging market economies a change in policy rates can exacerbate foreign capital flow volatility, in a CBDC framework it could also trigger sudden shifts between CBDC and commercial bank deposits.

However, unlike emerging market economies, where reserve requirements often serve as a *substitute* for the policy rate, in a CBDC framework the RR could mostly serve as a *complementary* measure, in parallel to conventional monetary policy. Thus, when an increase in the policy rate increases the spread between the bank deposit rate and CBDC remuneration (fixed at its upper bound), the central bank could raise the reserve requirement to offset the increase in bank deposits and to push the bank deposit rate back towards its previous level. Equally, when a cut in policy rates reduces the spread with the CBDC remuneration, the central bank could reduce the reserve requirement to offset a likely decline in bank deposits.[70]

Note that, from an operational point of view, the central bank could always directly observe the flows in and out of the CBDC accounts. In principle, this would permit a very quick response whenever the rise of a new flow imbalance might threaten financial stability or weaken the transmission of monetary policy. Appendix B provides an analytical description of this mechanism, using the CBDC framework of Section 3 derived from the works of Dutkowsky and VanHoose. The results are illustrated in Fig. 2 below.

[70] As a straightforward alternative, in this second case the central bank could lower the CBDC remuneration (via negative rates and/or higher user fees), in order to maintain the overall rate differential with bank deposits unaltered.

Fig. 2. Using reserve requirements to support interest rate policy in a CBDC framework: Case of monetary tightening ($q_1 > q_0$)



The figure shows that under certain conditions, an increase of the deposit rate – for example following a rise in the policy rate(s) – would generate a new equilibrium with higher rates and a bigger bank balance sheet (point e_1). This might happen, for instance, if changes to the policy rate have a greater impact on the volume of bank deposits than on the volume of bank loans. The central bank could then raise the RR ratio from q_0 to q_1, in order to rotate the deposit supply curve upwards, from $DS(q_0)$ to $DS(q_1)$. A higher q would act as a tax on bank liquidity out of deposits, since a higher share of this liquidity would receive a lower remuneration (the rate on required reserves). In the short-term, banks with no excess liquidity[71] would be obliged to liquidate their most liquid assets, i.e., domestic government debt, G, moving from e_1 to e_2. This would result in an even higher level of rates for government debt and bank lending, as well as in a higher marginal cost of funding (the slope of $DS[q_1]$ compared to $DS[q_0]$), which would ultimately contain the deposit rate increase, along with

[71] If banks have enough excess reserves, one could think that the effects of a tighter RR ratio on rates and volumes for lending and deposits would be null. However, since the Eurosystem remuneration of excess reserves is currently linked to the volume of required reserves (see Section 3), raising the RR ratio would automatically increase the average rate on excess reserves. This would drain liquidity from the market and reduce lending volumes (cf. DVH, 2018b). In practice, in a monetary system with heterogeneous distribution of excess reserves, such as the Eurosystem, the simultaneous use of both tools – policy rate and RR ratio – might be needed.

the size of bank balance sheets. Note that this outcome conforms to the typical textbook theory on the effects of RR, just as in the case of emerging countries with flexible exchange rates.[72]

As with the CBDC's negative interest rate, this particular use of RR would also target the same externality problem linked to excessive liquidity fluctuations. Therefore, it aims to generate an analogous effect: A kind of Pigouvian tax would apply in this case on bank deposits rather than on the CBDC, in order to reduce flow volatility between the two. In truth, the idea of controlling private money creation and financial stability with monetary policy instruments in general, and with RR in particular, is not new. While this approach is common in the emerging countries' literature on RR,[73] it finds a solid theoretical background also in recent studies focusing on the interrelation between monetary policy and macroprudential regulation in advanced countries, and on the new role of central banks in this context.[74]

6. Conclusion

This study clarifies two conditions that would allow the introduction of a retail digital euro on a large scale to avoid bank disintermediation or a credit crunch. First, the central bank would need to set up mechanisms to control the volume of CBDC. This would allow the central bank to issue CBDC only up to a level consistent with the current monetary policy stance, e.g., not triggering the absorption of more excess reserves than those deemed unnecessary for the effectiveness of unconventional monetary policies. Since the current level of excess liquidity amounts to 4.3 trillion euro, a conservative back-of-the-envelope estimation calibrated on pre-crisis conditions suggests that a CBDC issuance level slightly above one trillion euro might be plausible. Two natural candidates for managing CBDC volumes without imposing hard ceilings are *i)* the CBDC's overall rate of return (inclusive of charges and fees), and *ii)* banks' reserve requirements.

Second, the central bank should continue to facilitate access to its long-term lending facilities for as long as necessary to provide a cost-equivalent source of funding to banks without adequate excess reserves to cover client deposits converted to CBDC. For this purpose, the central bank would need to act on four fronts:

1) It should perpetuate its FRFA tender procedure, in order to guarantee a constant (low) marginal cost for central bank borrowing;

2) It should maintain a very broad collateral framework, allowing banks to mobilize the largest possible amount of non-marketable assets in their balance sheets as collateral, in order to keep the opportunity cost of funding via central bank borrowing comparable to that of funding via deposits;

[72] See Brei and Moreno (2019) for recent empirical evidence of this mechanism.
[73] Cf. Barroso et al. (2017) and Cantú et al. (2019), for instance.
[74] See Kashyap and Stein (2012), and Stein (2012), among others.

3) It should continue to implement lending operations with long maturities (above one-year), to support the preservation of adequate funding ratios by banks using central bank borrowing to replace lost deposits;

4) It should encourage a lighter regulatory treatment of assets encumbered for central bank borrowing, again to ensure that banks substituting deposits with central bank borrowing are not penalized by a higher NSF ratio.

The good news is that most of these measures have been in place in the euro area for longer than a decade, and their use has been further extended during the pandemic. Thus, we are certainly not in uncharted waters. If a retail CBDC were introduced on a large scale under these conditions, banks substituting lost deposits with central bank borrowing could easily maintain their lending volumes. In any case, banks with sufficient excess reserves to cover deposit losses could proportionately increase their profitability and competitiveness relative to non-bank lenders, while accelerating the transition to a new business model more in line with the digital economy of the twenty-first century.

At the macro level, the proposed CBDC design should prevent a massive disintermediation of banks, as well as the complete abandonment of cash as a payment instrument and especially as a store of value. Nonetheless, after the introduction of CBDC, a higher proportion of (unused) base money would be held outside the banking system, reducing the variability of the money supply. By attenuating the influence of inside money, CBDC would reduce an important source of procyclicality for the money supply, therefore improving financial stability while abating any potential risk of excess reserves for price stability (Bassetto and Phelan, 2015).

The impact on the monetary base would critically depend on the share of banks that would not be able (or willing) to shrink their balance sheet by using excess reserves to cover lost deposits. These banks would likely have recourse to central bank borrowing, thus inflating the central bank balance sheet. However, having eliminated any substantial friction for central bank borrowing as a bank funding substitute for lost deposits, the initial effects of CBDC on the money supply would be broadly neutral, without any contractionary effect on bank lending.

For monetary policy implementation, allowing non-banks to access central bank reserves would disclose a more direct path to influence economic conditions in the real economy. By controlling the volume and the user cost of CBDC, the central bank would have a powerful tool to better drive liquidity in and out of the banking system as needed. In the euro area, the CBDC setup needs to take account of the large heterogeneity in excess reserves across banks in different countries. The analysis shows that this does not represent a big obstacle, provided that the CBDC design and accompanying measures are properly devised. Indeed, a digital euro could even contribute to generate more homogeneous conditions across banks and countries, by mopping up large amounts of idle (and expensive) excess reserves without penalizing bank lending. This is important as excess liquidity nearly doubled during 2020, reaching the unprecedented record of 3.3 trillion euro at year-end, and it is likely to increase further in the near future under the effects of unconventional monetary policy and other crisis-related factors. Introducing a digital euro could then offer an additional tool for reabsorbing all the unnecessary excess reserves, taking into account that the current negative Deposit

Facility rate implies that banks on aggregate have to pay more than 13 billion euro per year to hold these funds at the central bank.

Clearly, the CBDC-feasibility conditions outlined above would imply a more active role for the central bank. From a crisis role as *lender of last resort* and *market-maker of last resort* (BIS, 2020a), the central bank could become a sort of systematic *auxiliary funding provider* for banks. While this sounds like the recent history of the Eurosystem, so far this role was considered temporary and contingent on crisis conditions. Permanently adopting such a role would likely render the central bank more visible and, therefore, more liable to political interference that could ultimately undermine its independence. Hence, central bank borrowing could become even more rule-based, to guarantee impartiality and preserve the central bank's reputation. In spite of its relevance, this topic transcends the scope of the present analysis, which aimed essentially to identify technical measures necessary to preserve bank intermediation and prevent disruptions to monetary policy and financial stability from the introduction of a digital euro.

Further work is certainly needed to confirm the conclusions of this study on the basis of empirical data, also in relation to the long-term implications for the financial system from 2020 developments in excess reserves and other variables. The Eurosystem has promptly reacted to the latest events by deploying a wide set of monetary policy measures, whose outcome will only become clearer over the coming months. Meanwhile, the pandemic is accelerating the process of financial digitalization, and changing the payment habits of large parts of the population. Central banks cannot rely exclusively on private payment providers and operators, if they are to pursue the public interest and address various risks in this vital field of modern economies. This explains much of the Eurosystem's interest for exploring benefits and risks of a digital euro, and it makes a compelling case to study the necessary conditions for its smooth introduction.

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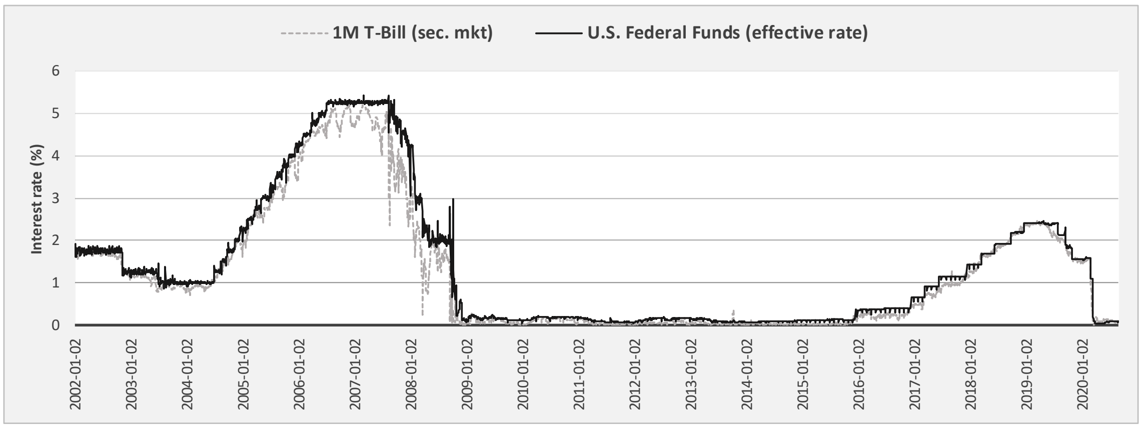
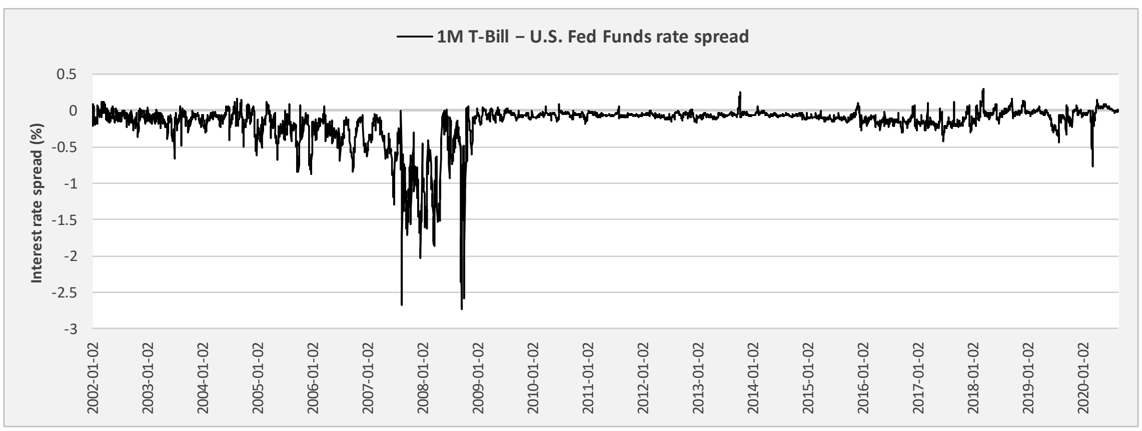
Appendix A:

Additional charts

Charts A1a-b. A historical comparison between the one-month US Treasury bill yield and the federal funds rate

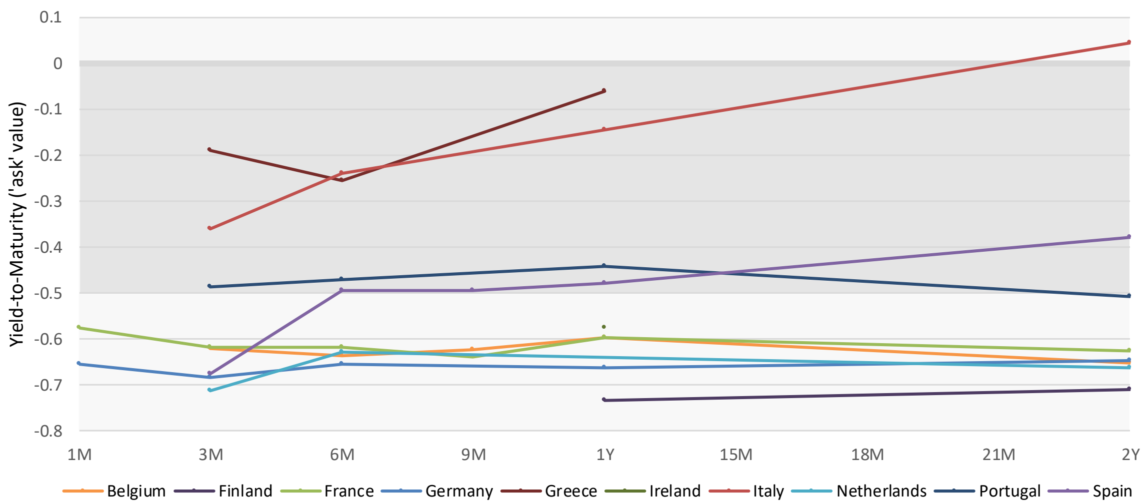




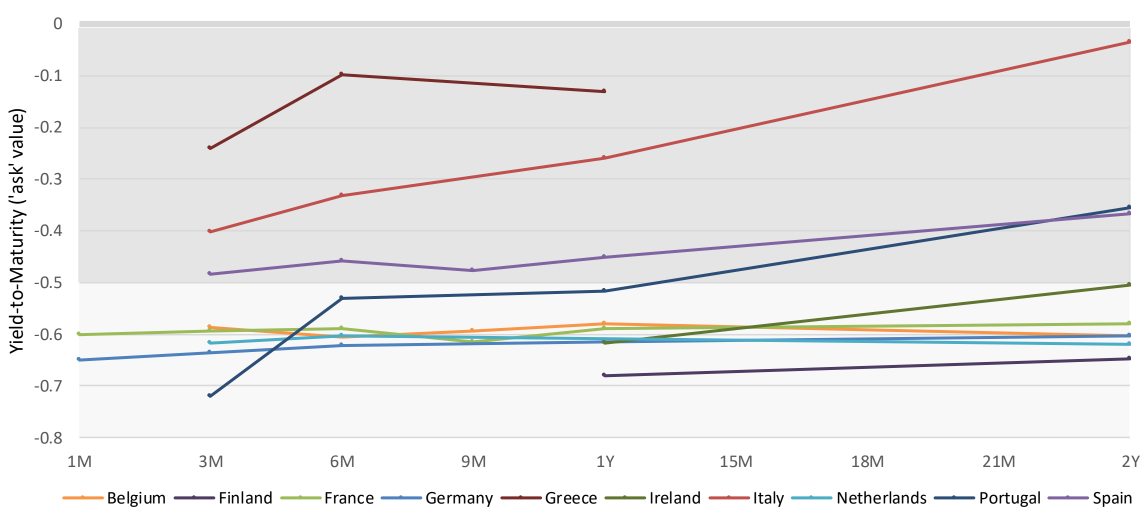
Source: Bloomberg.

Charts A2a-f. Short-end EUR Sovereign yield curves for selected euro area countries (Note: Dark-grey shadowed areas delimit the range of excess reserves' average remuneration)

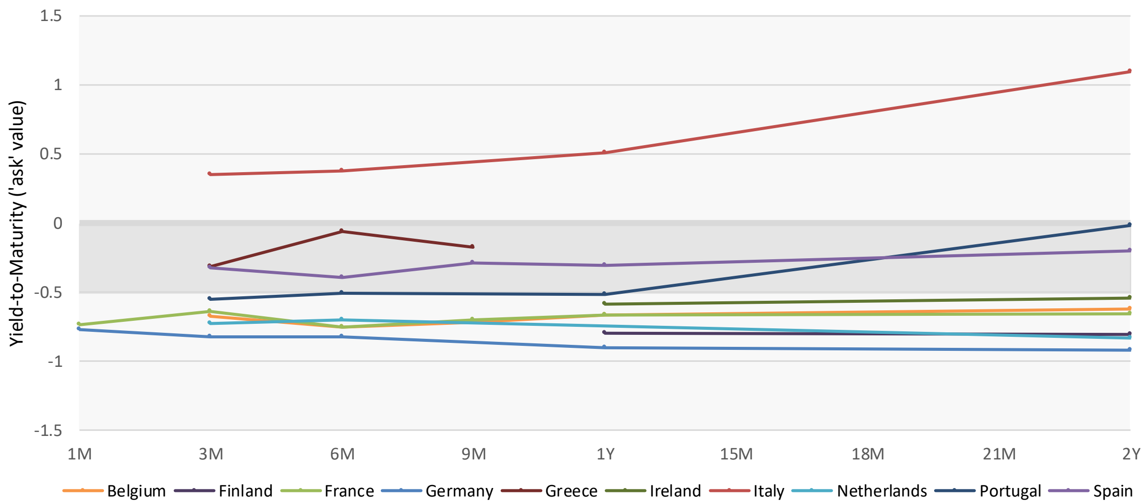
a. Date: November 15, 2019



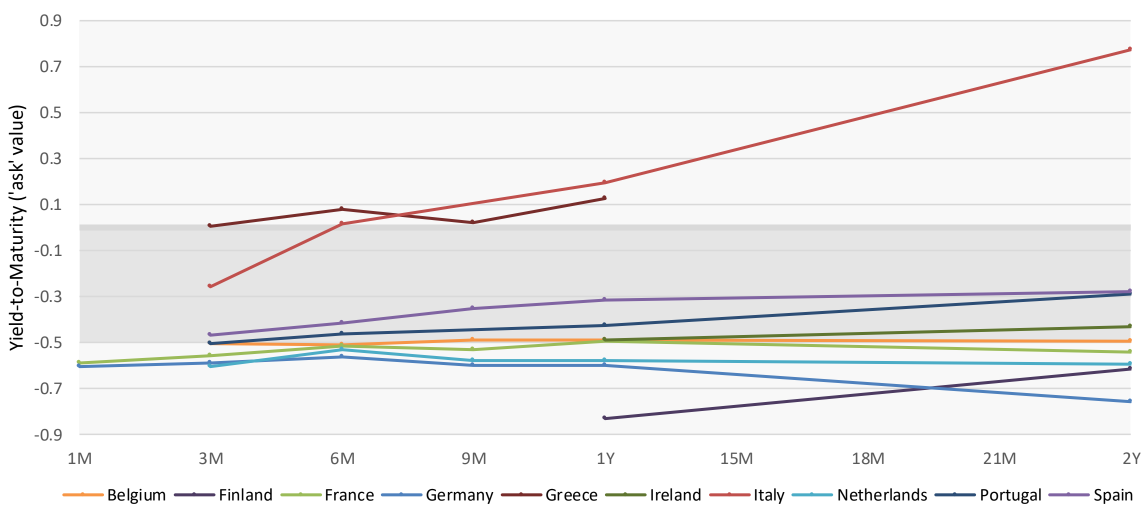
b. Date: January 15, 2020



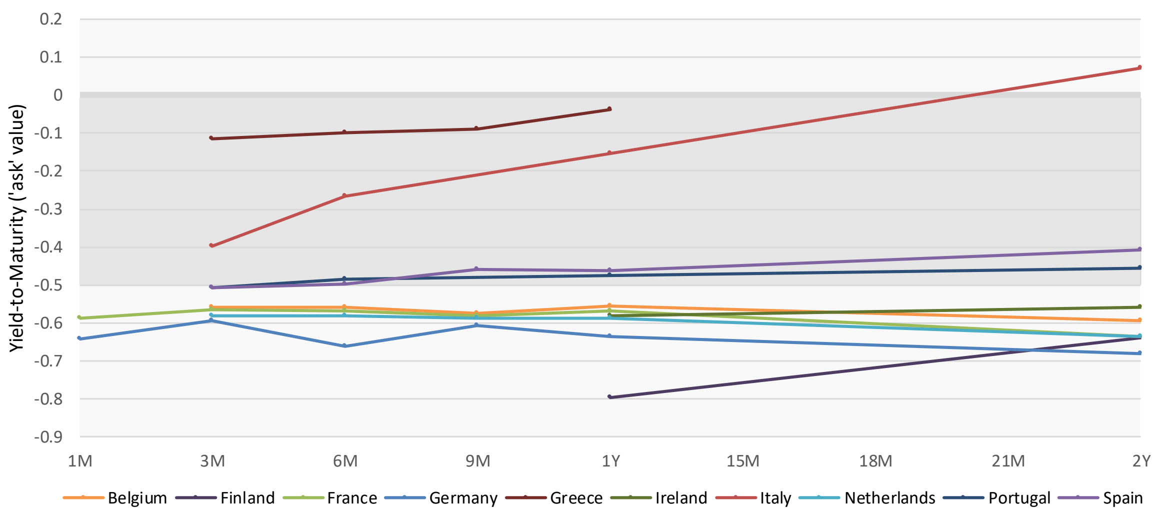
c. Date: March 16, 2020



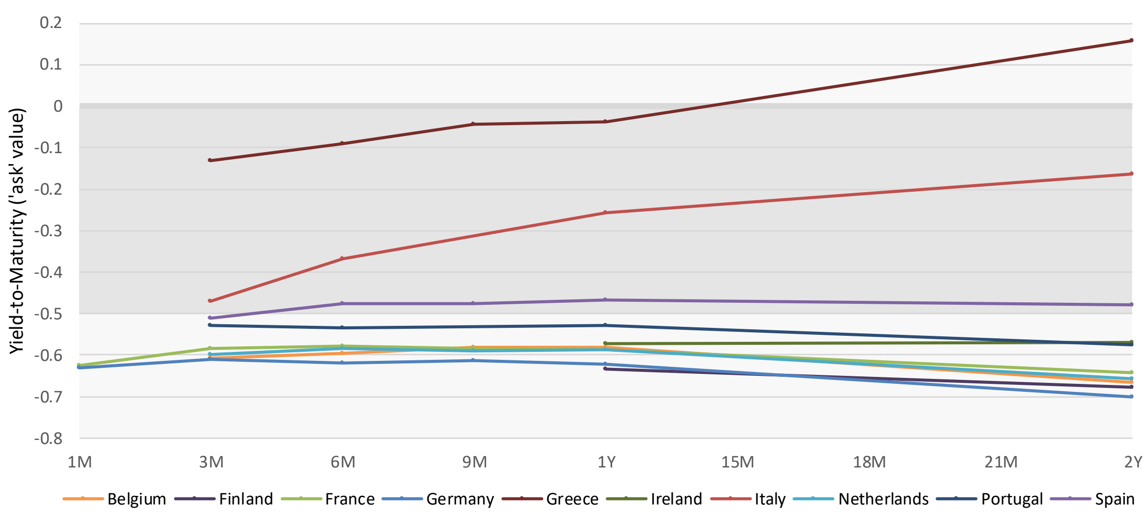
d. Date: May 15, 2020



e. Date: July 15, 2020



f. Date: September 15, 2020



Source: Bloomberg.

Appendix B:

The reserve requirement tool in the euro-adjusted version of the DVH framework

As explained in Section 5.2, in our euro CBDC framework, RR could be used as a complementary measure, in parallel to a move of the policy rate, whenever the latter lies well above zero, so that its differential with the CBDC rate creates the conditions for increased flow volatility between CBDC and bank deposits. The central bank could then raise (lower) the reserve requirement on bank deposits when an increase (decrease) of the policy rate raises (reduces) the differential with the CBDC rate, in order to offset a surge of the public's supply of bank deposits and to push back the deposit rate towards the previous level. This Appendix provides an analytic illustration of this mechanism, graphically represented in Fig. 2 above.

Recall from Section 3 that one of the first-order conditions for profit maximization for banks operating in a regime of positive excess reserves can be re-written as

$$qr_Q - r_D - \delta D + (1-q)r_X = 0 \tag{A2.1}$$

In addition to the previous assumptions, we expound the dependence of the deposit supply, B, from the CBDC rate, r_{CBDC}. Therefore, we model $\overline{D}$, the exogenous component of B, as

$$\overline{D} = \bar{d} + \omega \cdot (r_B - r_{CBDC}) \tag{A2.2}$$

where $\bar{d}$ is the truly exogenous, non-CBDC-related component, and ω is a positive parameter. This allows us to rewrite B as

$$B = \overline{D} + \varepsilon r_B = \bar{d} + (\omega + \varepsilon)r_B - \omega r_{CBDC} \tag{A2.3}$$

Recalling that in a positive excess reserve regime $D \cong B$, $r_D \cong r_B$, and $q \cong q_R$, then we can re-write (A2.1) as

$$r_B + \delta\left[\bar{d} + (\omega + \varepsilon)r_B - \omega r_{CBDC}\right] = q_R r_Q + (1 - q_R)r_X$$

from which

$$r_B = \left[q_R r_Q + (1 - q_R)r_X + \delta\left(\omega r_{CBDC} - \bar{d}\right)\right]/[1 + \delta(\omega + \varepsilon)] \tag{A2.4}$$

The expression (A2.4) shows that the deposit rate, r_B, can be affected by two policy rates: *i)* the required reserves rate, r_Q, and *ii)* the excess reserves rate, r_X. Supposing that the central bank decides to maneuver only the latter, it is trivial to verify that

$$\frac{\partial r_B}{\partial r_X} = \frac{1 - q_R}{1 + \delta(\omega + \varepsilon)} > 0$$

and

$$\frac{\partial r_B}{\partial r_X \partial q_R} = -\frac{1}{1 + \delta(\omega + \varepsilon)} < 0$$

which explains the mitigating effect of RR on the deposit rate (and deposit supply) increase triggered by a rise of r_X, following the mechanism illustrated in Fig. 2.

Notice that, more generally, this contractionary effect of q_R on r_B is conditional on a decrease of the differential between the remuneration of required reserves and that of excess reserves:

$$\Delta_{r_Q - r_X} = r_Q - r_X$$

Given that:

$$\frac{\partial r_B}{\partial q_R} = \frac{\Delta_{r_Q - r_X}}{1 + \delta(\omega + \varepsilon)}$$

it follows that

$$\frac{\partial r_B}{\partial q_R \partial \Delta_{r_Q - r_X}} = \frac{1}{1 + \delta(\omega + \varepsilon)} > 0$$

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