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Peter Karadi, Dominik Thaler, Oreste Tristani

The central bank's balance sheet in the long run: a macro perspective

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Discussion papers

Discussion papers are research-based papers on policy relevant topics, offering a broader and more balanced perspective. While being partly based on original research, they place the analysis in the wider context of the literature on the topic. They also consider explicitly the policy perspective, with a view to develop a number of key policy messages. Their format offers the advantage that alternative analyses and perspectives can be combined, including theoretical and empirical work. The selection and distribution of discussion papers are subject to the approval of the Director General of the Directorate General Research.

Abstract: We study whether it is desirable for the central bank to supply reserves abundantly, i.e. beyond the level that satisfies financial institutions' aggregate liquidity needs. Using a theoretical framework, we demonstrate that abundant reserves would help fulfil the private sector's demand for safe and liquid assets, because reserves affect financial institutions' leverage constraints. More specifically, systematic central bank purchases of medium-term government bonds from financial institutions would relax those institutions' leverage constraints and allow them to expand their balance sheets and issue more private liquidity, in the form of deposits. However, a very large increase in the average size of its balance sheet would expose the central bank to the risk of large financial losses. On balance, only a moderately larger supply of reserves than the level that satisfies financial institutions' aggregate liquidity needs appears desirable.

JEL: E41, E44, E58.

Keywords: Central Bank Reserves, Liquidity Policy, Friedman Rule

Non-Technical Summary

We study whether it is desirable for the central bank to supply reserves abundantly, i.e. beyond the level that is necessary for financial institutions to satisfy their aggregate liquidity needs.

The first section of the paper surveys the evidence demonstrating that safe and liquid assets were undersupplied before the Great financial crisis but became more abundant with the large increase in central bank reserves accompanying the implementation of unconventional monetary policy measures. This evidence suggests that a permanent increase in the supply of central bank reserves, through what we define as “extended liquidity policy”, could be beneficial. However, central bank reserves can only be held by financial institutions. Would the increased bank liquidity contribute to satisfy the liquidity demand of the rest of the non-financial private sector? What would be the side effects of an extended liquidity policy on the financial risks of the central bank?

In the second section of the paper, we answer the first question relying on a theoretical model. More specifically, we study whether a large stock of reserves systematically available for financial institutions would induce them to create more liquidity for the non-financial sector, in the form of bank deposits. We demonstrate that this should be the case because reserves affect banks’ leverage constraints. Since reserves have a lower risk weight than other assets, including government bonds, central bank purchases from banks of medium- and long-term government bonds would relax banks’ leverage constraints. They could therefore expand their balance sheets and issue more deposits. We conclude that an extended provision of central bank liquidity is likely to translate into an increased availability of liquidity also for the non-financial private sector.

We discuss the effects of an extended provision of liquidity on the risk exposure of the central bank in the last section of the paper. A larger balance sheet could lead to occasional marked-to-market losses for the central bank. While central bank losses are not problematic per se, they may, if large, lead to a loss of control over inflation. These considerations restrict the scope for an extended liquidity policy. Furthermore, they favour a composition of the balance sheet tilted towards safer assets and lower maturity transformation.

Overall, an extended liquidity policy would produce some benefits, but also side effects. On balance, a moderately larger supply of reserves than prior to the global financial crisis appears desirable. It would help satisfy the private sector’s liquidity demand while minimising the ensuing financial risk for the central bank.

1 Introduction

In many industrial countries the stock of reserves increased considerably after the Global financial crisis, as a result of the deployment of various forms of unconventional monetary policy measures. As those measures are slowly reabsorbed, it is natural to ask whether the supply of reserves should be reduced proportionally, or whether it should remain abundant, and to what extent. A certain increase in the structural level of reserves appears necessary, for example because financial institutions are likely to use reserves to fulfil new liquidity requirements. Limiting the increase to such minimally higher level would be consistent with the pre-crisis practice and with the principle of minimising the market footprint of the central bank. A larger level of reserves would arguably help to satisfy the private sector's demand for safe and liquid assets.

The first section of the paper reviews the evidence on the demand for safe and liquid assets. The empirical literature based on the U.S. has considered as liquid all short-term assets issued by the public sector, including central bank reserves and short-term Treasury bills. The steep slope that used to characterise the Treasuries' yield curve at very short maturities before the financial crisis is considered as an indicator of a liquidity premium that investors are willing to pay to hold liquid assets. Despite the short available sample period, we show comparable evidence for AAA treasury securities also in the euro area. This evidence suggests that short-term safe and liquid assets were undersupplied before the large expansion of central bank reserves that occurred with the financial crisis.

One option to satisfy this demand is for Treasuries to issue more short-term bills or swap long-term bonds for short-term bills. Since Treasuries are tradable, they would provide liquidity to the whole private sector. A second option is to increase the supply of central bank reserves through what we define as "extended liquidity policy". Compared to increasing the supply of Treasuries, extended liquidity policy would only provide liquidity to financial institutions. Since banks would need to hold large quantities of reserves, this policy also risks crowding out the supply of bank credit. Is an extended liquidity policy at all desirable? Would at least part of the increased liquidity spill over to the non-financial sector?

In the second section of the paper, we rely on a theoretical model to answer this question. The premise of the model is that the return on safe and liquid assets will tend to incorporate a premium, which can also be viewed as the opportunity cost of holding these assets instead of other risk-free assets that do not provide liquidity services. We then ask whether the premium on liquid assets held by the non-financial private sector, such as bank deposits or short-term Treasuries, can also be expected to fall, as the central bank provides increasingly large amounts of reserves.

We answer the question in two steps. In the first step we identify a theoretical condition which may warrant a bounded supply of central bank reserves, notably a supply below the satiation level recommended by the Friedman rule, or, equivalently, a remuneration of reserves below the market rate. The condition is that financial institutions be subject to a leverage constraint applying to their total assets. Due to the constraint, financial intermediaries need to finance their internal capital, and therefore require a spread between the return on their assets and the cost of their liabilities (deposits). The equilibrium return on deposits must therefore be lower than the return on the assets held by intermediaries, including reserves. As long as reserves have a lower risk weight than other marketable short-term assets, their remuneration should also remain below the short-term market rate. From the perspective of the non-financial private sector, the opportunity cost of holding liquid bank deposits will be non-zero.

In the second step, we discuss whether the opportunity cost can nevertheless be reduced through an extended provision of central bank liquidity in the form of a permanent programme of medium- and long-term government bond purchases from financial institutions. We show that, as long as reserves have a lower risk weight than government bonds, for example because they are not subject to interest rate risk, swapping them for government bonds would relax financial institutions' leverage constraints. This, in turn, would allow these institutions to expand their balance sheets, and issue more deposits. Therefore, an extended provision of central bank liquidity is likely to also translate into an increased availability of liquidity – in the form of bank deposits – for the non-financial private sector. This policy would therefore be beneficial. Abstracting from other considerations, the scale of the asset purchases should be large.

However, an extended provision of liquidity would produce implications on the central bank's exposure to financial risk. While incurring losses is not immediately problematic for central banks, because they have the unique ability to issue money and losses do not automatically pose solvency problems, very large losses may eventually imply losing control over inflation if, for example, the government is unwilling to recapitalise the central bank though a fiscal transfer. These considerations restrict the scope for an extended liquidity policy. Furthermore, they favour a composition of the balance sheet tilted towards safer assets and lower maturity transformation. A partial qualification of this conclusion is that, as shown by the recent experience, central bank losses may nevertheless be incurred during the recovery following the deployment of QE-type interventions. Assuming that such losses in bad times are unavoidable, they could be partially compensated by average gains if the central bank held a non-zero asset portfolio also in good times.

Overall, extending central bank liquidity is not without side effects, therefore the complete elimination of the liquidity premium through abundant liquidity provision is undesirable. In other words, the Friedman rule is a useful benchmark, but it needs to be qualified. The side effect we focus on points out that reserves can only be held by banks, which face binding balance-sheet constraints. Reserves, therefore, can crowd out beneficial lending opportunities and an overly low liquidity premium can adversely affect banks' profitability and, thus, limit their lending capacity. Furthermore, assets held by the central bank as a counterpart of its reserve creation can lead to undue exposure to financial risk. On balance, evidence indicates that pre-financial crisis central-bank liquidity provision might have been overly scarce. A somewhat larger balance sheet that satisfies more liquidity demand, while keeping side effects contained, would therefore be justified.

2 The central bank balance sheet as a tool for extended liquidity policy

Figure 1 provides a stylised characterisation of the central bank balance sheet. On the assets side, the balance sheet can include holdings of government bonds and lending operations to financial institutions. On the liabilities side, one finds currency circulating in the public and reserves held by financial institutions, plus the capital of the central bank. Currency and reserves, or the monetary base, are the key monetary policy-related variables that affect the overall size of the central bank balance sheet. Since the amount of currency circulating in the public does not change too much over time, to a first approximation the size of the balance sheet is driven by the amount of reserves.[1] We therefore abstract from cash in the paper.

Figure 1

Stylised central bank balance sheet

assets	liabilities
gov't bonds (R^b)	cash
lending to banks	reserves (R^m)
	capital

Note: *Rb* and *Rm* will denote the gross rates of return on government bonds and reserves, respectively.

The amount of reserves is often left unspecified in modern treatments of monetary policy. This approach is based on the view that the objectives of monetary policy can be achieved, and are achieved in the practice of central banks, at least in normal times, through the appropriate setting of a short-term interest rate. Such interest rate can be set through open market operations or, as in the euro area case, through collateralised lending operations with banks. These operations will be recorded in the central bank balance sheet, triggering a demand for central bank liquidity and the creation of reserves. As long as the demand for liquidity is satisfied, the exact quantity of reserves that is created is inconsequential for the determination of the monetary policy stance. Interest rate policy and reserves supply policy can be set independently of each other.[2]

[1] Currency in circulation has followed an increasing trend since the start of EMU. Nevertheless, its dynamic has been contained compared to the changes recorded in the amount of reserves.

[2] See, for example, Curdia and Woodford (2011).

2.1 Financial institutions’ liquidity needs

While a short-term interest rate determines the monetary policy stance, the supply of reserves ensures that the appropriate amount of central bank liquidity is available to the financial system. A demand for liquidity could arise from transaction needs, or to fulfil the desire to maintain a buffer of liquid savings. Idiosyncratic needs may be satisfied through interbank transactions, but the residual liquidity demand of the aggregate banking system must be satisfied by the central bank.

In theory, liquidity supply could be determined by the central bank in two ways. A first approach would be to directly specify its quantity. This approach could be cumbersome in practice if aggregate liquidity demand is subject to large, stochastic changes over time, for example in reaction to liquidity-preference shocks. The central bank would need to assess at a high frequency the appropriate quantity of reserves to supply, depending on demand conditions. A second approach is to affect the quantity of liquidity indirectly, by setting its opportunity cost, and letting the quantity be demand-determined.

This second approach has similarities with the practice of the ECB after the financial crisis.[3] Over this period, central bank liquidity was abundant and the remuneration of excess reserves became very close to the overnight rate. It is expected that this will also be the case in the future (see Schnabel, 2024, for a discussion of the new ECB operational framework).[4]

In practice, financial institutions’ demand for reserves will be at least as large as necessary to satisfy minimum liquidity needs. At the aggregate level, and abstracting from periods of financial disruption, minimum liquidity needs are traditionally determined by reserve requirements and by so-called autonomous factors, such as government deposits.

For given reserve requirements, the quantity of reserves increases with the stock of bank deposits. The left panel of Figure 2 presents evidence of a secular increase in bank deposits in the euro area both in nominal terms and as a share of GDP. The increase in deposits raises the structural liquidity demand of banks, which, therefore, can be expected to be higher than before the Global Financial Crisis.

After increasing markedly during the period of negative interest rates, autonomous factors are expected to become smaller in the future, but they also appear to have become more unpredictable (Baldo et al., 2017; Kinsele and Lizarazo, 2022). A somewhat larger liquidity supply may thus be desirable for precautionary reasons, that is to avoid that unexpected increases in autonomous factor subtract liquidity from financial institutions.

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[3] Before the financial crisis, the ECB used to remunerate “excess reserves”, i.e. reserves in excess of the amount required to satisfy the reserve requirement, at a rate lower than the (overnight) market rate. This approach implied that excess reserves carried an opportunity cost. However, the quantity of excess liquidity provided to banks was capped by the ECB, it was not demand-determined.

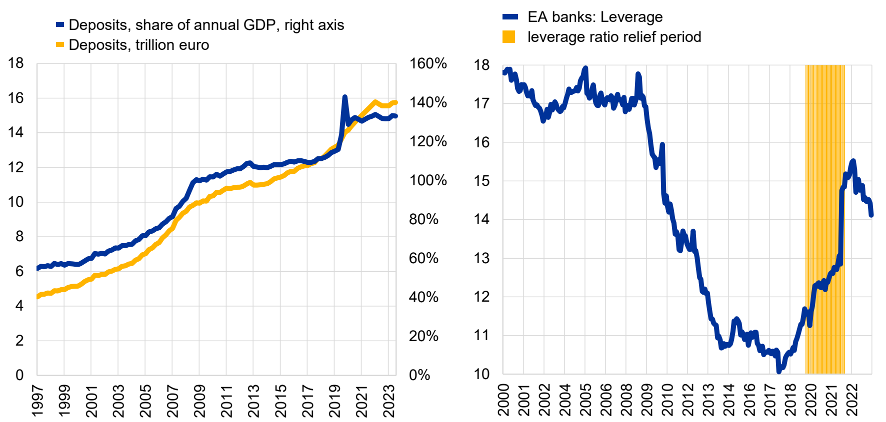
[4] Required reserves are an exception. On 27 July 2023, the ECB had already decided that required reserves would no longer be remunerated.

A final factor that is likely to have caused a structural change in the demand for central bank reserves are the new banking regulation measures introduced after the Global Financial Crisis. These were either aimed to ensure sufficient capital against any bank exposures, the leverage ratio, or to limit liquidity risk, the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR). While the leverage ratio limits the demand for reserves, the LCR and NSFR are likely to raise it.

Figure 2

Evolution of bank deposits and bank leverage in the euro area

Bank deposits (left). Euro area bank leverage (right).



Source: European Central Bank, Eurostat.
Note: The left panel shows the evolution of the bank deposits in the euro area both in nominal terms and relative to annual GDP. In particular, it shows the deposits of the general government and the private sector in the consolidated euro area MFI balance sheet. The right panel shows the evolution of the ratio between total assets of the aggregate banking sector and their equity (capital plus reserves).

The regulatory leverage ratio can be expected to limit banks' demand for central bank reserves, because larger reserves holdings must be accompanied by an increase in internal funds. The Basel Committee on Banking Supervision introduced the leverage ratio in the 2010 Basel III package of reforms. As of 2018 the leverage ratio became a binding requirement. The right panel of Figure 2 shows that this measure started producing effects very quickly. Aggregate leverage of the euro area banking sector, represented in the figure by the ratio between total assets and internal equity, fell significantly between 2010 and 2013. Despite the launch of the ECB's Asset Purchase Programme in 2015, bank leverage remained stable until 2019 and only increased again with the outbreak of the COVID-19 pandemic, when the leverage ratio was temporarily suspended.

By contrast, the LCR requirement can structurally increase banks' demand for reserves. It requires banks to hold a stock of high-quality liquid assets above a certain reference level, and central bank reserves above the reserve requirement qualify as high-quality liquid assets. Similarly, liquidity providing operations with a residual maturity above one year can be used to improve banks' NSFR, which aims at limiting banks' liquidity and maturity transformation (Sugo and Vergote, 2020).

In sum, the demand for liquidity of the banking sector appears to have increased. Central bank reserves will therefore have to increase accordingly, to ensure that the banking sector can satisfy its liquidity needs.

In the rest of this section, we review the literature calling for an increase in reserves beyond such minimum level. We define this approach as “extended liquidity policy”. We review available evidence on the broader private sector’s demand for safe and liquid assets and some conceptual arguments on the desirability of an extended liquidity policy. By and large, we conclude that this policy has some benefits, but it also entails costs.

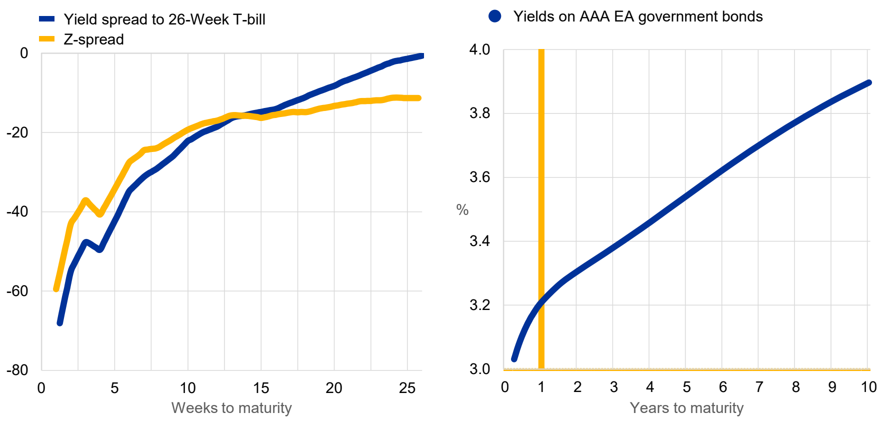
2.2 Scarcity of liquid and safe assets

There was an excess demand for interest-bearing, money-like instruments that are both liquid and safe before the Great Financial Crisis. Greenwood, Hanson, and Stein (2016) show that the US Treasury yield curve had an excess steepness at very short maturities – see the left panel of Figure 3. This is suggestive evidence on the existence of a liquidity or ‘moneyness’ premium that investors are willing to pay to hold these short-term assets, over and above their pecuniary return. The evidence also suggests that the amount of reserves supplied by the Fed at the time was not sufficient to fully eliminate this liquidity premium.

The right panel of Figure 3 presents related evidence for the euro area. In particular, it shows the shape of the euro area AAA yield curve before the financial crisis. In line with the US evidence, the slope of the yield curve below 1-year maturity is in excess of its slope above 1-year maturity. The positive premium is consistent with the assumption that these short-term safe assets were undersupplied also in this region.

Figure 3
Moneyness premium in the US (Greenwood et al., 2016) and Euro Area

Yield spreads on US Treasury Bills (left). Yields on AAA EA government bonds (right).
(Left: basis points. Right: %.)



Source: Greenwood-Hanson-Stein, 2016, Chart 3A (left figure), European Central Bank (right figure)

Note: The figures show average yields and yield spreads of US and euro area government bonds. The left panel plots the average spread, over the period 1983 to 2009, between T-bill yields of maturities from one to 26 weeks and the yield on the 26-week bill. It also plots the z-spread, defined as the difference between T-bill yields and fitted yields, where fitted yields are based on the flexible extrapolation of the Treasury yield curve from Gürkaynak, Sack, and Wright (2007). The right panel plots the average yield, over the period 2004-2008, of fitted AAA euro area government bond yields of maturities 3 months and 10 years relying on the daily ECB yield curve estimates.

Why cannot the private sector satisfy the excess demand for liquid and safe assets? Stein (2012) argues that a potential reason is a well-understood innate tension between liquidity and safety. Liquidity requires that the asset can be sold at minimal loss at very short notice in case a sudden liquidity need arises. Banks can satisfy such needs by transforming illiquid, long-term investment into liquid deposits (Diamond-Dybvig, 1983). They can do this because liquidity needs of different depositors normally arise in a staggered fashion. The safety issue related to such deposits arises because of a coordination problem: the bank cannot satisfy the liquidity need of all its depositors at the same time in case of a bank run. The reason is that the illiquid assets it holds cannot be sold at short notice without fire-sale losses. In other words, the deposits, similarly to other privately created liquid assets (like mutual fund shares) are ‘runnable’ and therefore risky.

An argument for extended liquidity policy is that a large stock of reserves can help mitigate the scarcity of liquid assets and potentially eliminate the moneyness premium. The reason is that reserves are safe public liquid assets, so the central bank is in a good position to address this market failure (Greenwood, Hanson, Stein, 2016). The central bank can achieve this by maintaining a structural long run balance sheet that replaces less liquid long-term government bonds and bank loans with liquid reserves.

2.3 Scarcity of reserves versus scarcity of convenient assets

Lopez-Salido and Vissing-Jorgensen (2023) provide additional evidence from the US, which shows that higher reserve supply indeed increases the liquidity of banks and reduces liquidity premia in the interbank market. In particular, they document a stable negative relationship between reserves and the interbank-rate spread and a positive relationship between bank deposits and the interbank spread. Vissing-Jorgensen (2023) shows that a similar stable relationship exists in the euro area as well. Both papers emphasise that the gains from this liquidity provision need to be balanced with the risks coming from reserves partially crowding out the supply of bank credit to the private sector.

An adverse effect of increasing the supply of reserves through purchases of government bonds is the corresponding reduction in the stock of government bonds available to the private sector. Krishnamurthy-Vissing-Jorgensen (2012) and Vissing-Jorgensen (2023) show that government bonds issued by safe sovereigns, like the US or Germany carry a ‘convenience yield’, as investors derive convenience (utility) from their high liquidity and safety. Focusing on the AAA bonds, Table 1 shows an indicator of the convenience yield in the euro area, namely the spread between bond yields and the OIS rate for a corresponding maturity (where the OIS rate is used as a proxy for a pure, risk-free rate). The negative values reveal a convenience yield of safe government bonds. Low values at the shortest segments are consistent with the moneyness premium of short and safe government bonds discussed in the previous section, but the table shows that the convenience yield extends also to longer maturities.

Table 1
(%, average spread)

AAA – OIS spread	Pre-GFC (2005-2008)	Pre-APP (2009-2014)	APP (2015-2021)
3-months	-.15	-.10	-.25
2-years	-.13	-.02	-.25
10-years	-.09	.47	-.16

Source: authors' calculations and Bloomberg
The table shows average AAA-OIS spreads in the euro area between 2005-2021.

Swapping government bonds with a convenience yield for bank reserves can be expected to reduce the amount of convenience available in the market, especially in non-bank capital markets. The overall safety of assets is not expected to decline with the swap, and the overall public liquidity supply might even increase. But markets are segmented, and reserves can only be held by banks, which cannot always transform them into safe and liquid assets, which would be widely tradable across markets.

Furthermore, a restricted supply of long-term government bonds can reduce convenience of market participants with matching long-term liabilities (e.g. pension funds), which aim to hold these assets for their suitable hedging properties. Vissing-Jorgensen (2023) argues that the loss in convenience can be expected to be lower in the euro area if the ECB reverts to covering its reserves supply by structural long-term refinancing operations that are collateralised with assets without convenience. The advantage of this framework relative to outright asset purchases is that it leaves convenient assets in the hands of the private sector. As the convenience costs of a structural central bank balance sheet can be smaller, the desirable size of the balance sheet can be larger.

Overall, the desirable central bank balance sheet needs to balance the higher convenience of overnight reserves with the potential loss of convenience brought about by the reduction in the government bonds available to the private sector.

2.4 The multi-country nature of the euro area

Not only the central bank could mitigate liquidity scarcity: debt maturity policy of safe sovereigns could achieve the same by issuing relatively more short-term bonds. The policy can lead to lower debt-servicing costs as the government can cash in on the liquidity premium. A cost of such a policy is that shorter maturity debt could make interest expenses of the government more volatile. This should not matter for safe sovereigns, which can flexibly adjust their debt issuance to cover this cost and keep their primary balance smooth. However, treasuries of safe sovereigns can still worry about 'auction risk' (Greenwood, Hanson, and Stein, 2016), which is the prospect of insufficient demand for government issued assets at the primary markets, and it can make them prefer the issuance of longer-term assets with fewer auctions. Greenwood, Hanson, and Stein (2016) argue that debt maturity policy leads to the undersupply of US short-term government bonds. We have seen that the resulting moneyness premium showed up also in the AAA euro area yield curve.

Should central banks step in and mitigate the resulting liquidity shortage? One argument for this is that central banks do not face auction risk as they can create potentially unlimited amount of liquidity, so they can guarantee an absolute certainty of nominal repayment. Therefore, central banks might be in a better position than sovereigns to satisfy liquidity demand by maintaining a structurally large balance sheet. Central bank reserves can only be held by banks, but these might be able to transform reserves into liquidity for the wider market, even if it is unclear how much this type of transformation would operate in practice.

A further consideration in the euro area is that auction risk is heterogeneous. High yield countries are more exposed to confidence crises and may find it especially costly to tilt their debt maturity towards the short term. However, the ECB can play a role in mitigating the roll-over risk, by providing insurance against it through its role as a lender of last resort for the sovereigns. Such insurance is now explicit in the euro area through the ECB’s Transmission Protection Instrument (TPI), and its conditionality mitigates the potential for moral hazard.

3 Benefits of an extended liquidity policy

In this section, we review the theoretical results of the literature on the ideal level of the interest rate on reserves. We start from the Friedman rule, prescribing that the remuneration of reserves should coincide with the short-term rate. We then discuss theoretical conditions suggesting that the interest rate on reserves could be lower than the short-term rate. We subsequently discuss the possibility of issuing reserves via central bank asset purchases.

3.1 The Friedman rule for reserves policy

A very general result regarding the provision of central bank money (reserves) is the Friedman rule (Friedman, 1960). An intuitive proof of the Friedman rule can be found in Woodford (1990). It starts from the observation that reserves are not a scarce resource since their supply can be changed at no cost. A positive spread between the return on another short-term nominal asset, such as government bills, and the return on reserves can only exist if the marginal benefit of an additional unit of reserves is positive. But a positive marginal benefit of reserves is inconsistent with optimality if reserves are not a scarce resource.

A version of the Friedman rule can be derived in a simple model in which real money balances provide utility, alongside consumption and leisure. In this type of formulation, first used by Sidrauski (1967), a representative consumer seeks to maximise

$$\sum_{t=0}^{\infty} \beta^t u(c_t, n_t, m_t)$$

where c_t represents consumption in period t, n_t represents labour supply, and m_t represents real money balances, that are equal to the ratio between nominal reserves M_t held at the beginning of period t and the price level P_t in period t (the price of the consumption good in terms of money). Reserves are "money" in this simple model, and they enter utility to mimic a demand for money for transactions purposes. (To recall, we abstract from cash for simplicity.)

While providing utility services, money/reserve balances can yield a gross nominal interest rate R_t^m. Households can additionally hold a short-term government bond yielding a gross nominal interest rate R_t^b. Household choices include the following condition:

$$\frac{R_t^b - R_t^m}{R_t^b} = \frac{u_{m,t}}{u_{c,t}},$$

implying that the marginal benefit of reserves, $u_{m,t}$, must equal its marginal utility cost, $\frac{R_t^b - R_t^m}{R_t^b} u_{c,t}$. We take the interest rate R_t^b as given in this expression – the idea is that it will be determined by the central bank in order to set the monetary policy stance. Our focus will therefore be on the opportunity cost of holding reserves, which is represented by the $R_t^b - R_t^m$ spread.

Taking this condition into account as a constraint, the central bank in the model will set the return R_t^m so as to maximise household welfare. Since reserves can be produced costlessly by the central bank, it is optimal to increase their supply until households' demand is satiated, i.e. until $u_{m,t} = 0$. The equation shows that $u_{m,t} = 0$ requires $R_t^b = R_t^m$ at all times. The quantity of reserves will be fully demand-determined.

While the model sketched above is extremely simple, the intuition for the optimality of the Friedman rule holds in much more general settings. Woodford (1990) reviews the vast literature on the Friedman rule and demonstrates that it holds in many different models of the demand for central bank liquidity.[5] Cúrdia and Woodford (2011) extends the result to a less stylised model in which reserves are demanded by banks, rather than households, for financial intermediation purposes. Reichlin et al. (2021) draws recommendations for the balance sheet of the Eurosystem drawing on the Friedman rule intuition.

3.2 The Friedman rule with leverage-constrained banks

In the simple model sketched above, reserves are issued by the central bank and directly held by households. In reality, reserves can only be held by financial institutions. The type of money demanded by households, and by the rest of the non-financial private sector, is a form of liquid asset. Abstracting from cash, the obvious example of a liquid asset are demand deposits, that are issued by financial institutions. The rest of this section takes into account the role of financial intermediation for the determination of the interest rate on reserves.

A key feature of banks that we will take into account is that they are leverage-constrained financial institutions. The private sector is unwilling to fund them if their capital is very low. We capture this idea following the approach in Gertler and Karadi (2011). There are two key assumptions. First, households must pay a holding fee to invest in the financial market directly. Second, there is an agency problem that constrains the ability of financial institutions to attract deposits and gives rise to the leverage constraint. More specifically, the assumption is that a financial intermediary can abscond a given fraction of its assets, which would impose losses on depositors. Recognising this risk, depositors will limit the amount of funding they are willing to provide to a bank, which is tantamount to a leverage constraint.

The leverage constraint can be interpreted as a (market-induced) haircut requirement, that arises from the exposure to interest rate risk of most financial asset prices. The constraint is also consistent with the regulatory leverage ratio

[5] Most of the discussion in Woodford (1990) is devoted to the version of the Friedman rule conditional on the assumption that reserves are not remunerated. In this situation, the only possibility to ensure that the return on reserves is not dominated by the return on other nominal assets is for the central bank to set its main monetary policy rate permanently at zero. While this case is special, the intuition for the Friedman rule result carries over to the situation in which reserves are remunerated. This case is discussed at the end of Woodford (1990).

requirement, which applies to the ratio between a bank's capital and its assets, irrespective of how risky those assets are – see the right panel of figure 2.[6] We therefore assume that reserves are also subject to such requirement, so their return must also be higher than that on bank deposits. We also assume that the constraint is tighter for other bank assets, notably government bonds.

As in the case of the Sidrauski specification above, households demand liquidity services, but now these take the form of bank deposits.[7] The specification of the utility function is otherwise unchanged. When government bond holding fees are very small, households' optimal decisions will include the same condition as above, once reserves balances are replaced with deposit balances:

$$\frac{R_t^b - R_t^d}{R_t^b} = \frac{u_{d,t}}{u_{c,t}}$$

Following the same logic as Section 3.1, this condition suggests that the marginal utility of deposits should again be driven to zero if deposits could be "produced" costlessly by banks. So, the key question to assess the optimality of the Friedman rule is whether banks are able to satisfy in full the demand for liquid deposits at zero opportunity cost. In the model, their being subject to a leverage constraint is the key factor constraining their ability to do so.

For simplicity, we assume that banks, besides reserves, hold only government bonds.[8] Financial institutions will demand a spread between the return on government bonds and the return on deposits. The spread allows them to build capital, and thus have "skin in the game" when deciding the size of their balance sheet. Since banks need to hold the outstanding government bonds not held by households, it is no longer feasible to close the $R^b - R^d$ spread and ensure that households' marginal utility of deposits $u_{d,t}$ is zero. The Friedman rule intuition continues to hold, but the creation of inside money (deposits) is no longer costless, due to financial institutions' leverage constraint. The marginal benefit of deposits must also remain positive.

Taking into account that the opportunity cost of deposits cannot be set to zero and that reserves can only be held by financial institutions, what is the optimal setting of the interest rate on reserves, R^m? Since we assume that the leverage constraint is tighter for government bonds, these assets must also yield a higher return to banks, so that $R^m < R^b$. A simple equilibrium relationship between these two returns can be derived in the steady state of the model under the assumption that holding costs are very small:

$$\frac{R^m}{R^b} = 1 - (1 - \delta)\frac{1}{\phi - 1}\frac{\beta - (\theta + \omega)}{\theta + \omega} \leq 1,$$

[6] It would be interesting to also take into account the constraints imposed by liquidity regulation. See Porcellacchia and Sheedy (2004) for an alternative macro model with a role for liquidity. See also Piazzesi and Schneider (2021) for a different model of liquidity with leverage constrained banks.

[7] See Porcellacchia and Sheedy (2004) for an alternative macro model with a role for liquidity.

[8] We abstract from bank lending for simplicity.

where $0 \leq \delta \leq 1$ captures the extent to which reserves have a milder impact on the leverage constraint, compared to government bonds, ϕ denotes banks' target leverage (defined as total bank assets over capital), $\beta < 1$ is households' subjective discount factor and θ and ω are positive parameters in the bank's optimisation problem such that $\beta - (\theta + \omega) > 0$. The equation shows that $R^m/R^b = 1$ is possible in two cases. The first one occurs if $\phi \rightarrow \infty$, i.e. when financial institutions are not subject to the leverage constraint and the model de facto collapses to that in section 3.1. Secondly, $R^m/R^b = 1$ is possible if $\delta = 1$ and reserves have the same impact on leverage as government bonds.

Outside the model steady state, it is intuitively desirable to keep the $R^b - R^m$ spread constant over time since this simplifies banks' liquidity management. In the face of aggregate shocks to the demand for deposits, financial institutions need to be able to adjust the size of their assets if they are to maintain their leverage constant. A constant spread makes the opportunity cost of reserves independent of the level of the short-term rate. Financial institutions can then absorb liquidity shocks independently of when they occur over the business cycle.

3.3 Extended liquidity policy and leverage constrained banks

So far, we have specified the reserves-supply policy by setting its opportunity cost and satisfying the corresponding demand. Reserves were central bank liabilities without an explicit counterpart on the central bank balance sheet. We now consider the realistic case in which reserves are created through targeted purchases of government bonds held by financial intermediaries. Such purchases would be different from QE-type measures because they would take place on a permanent basis, rather than when the policy rates are constrained by the ELB, and because they would have the objective to provide additional liquidity to the economy, rather than being a means of monetary policy accommodation. To underline this difference, we refer to these purchases as extended liquidity policy. This option has been recommended in the literature surveyed in Section 2. Here, we discuss its desirability from a theoretical perspective.

A key question concerning the desirability of extended liquidity policy is whether it only benefits financial institutions, or also households. To analyse this question, we modify the simple approach sketched in Section 3.2 in two directions.

The first modification is to take into account that a broader definition of liquid assets includes short-term government bills, alongside bank deposits. More specifically, we assume that short-term government bonds also have strong liquidity/safety features, because they are not subject to price fluctuations. Like deposits, households will therefore demand them also for their liquidity benefits. We therefore explicitly introduce the maturity dimension in the model and differentiate between short-term and long-term government bonds. In equilibrium households will hold deposits and short-term Treasury bills, in this case without paying any holding fees. At the same time, we will assume that short-term bonds and bank deposits are not perfectly substitutable. Following Nagel (2016), we allow households to hold liquidity services, l_t, given by a convex combination of deposits and short-term government bonds. In this case, household optimality requires

$$\frac{R_t - R_t^d}{R_t} = \frac{u_{l,t}}{u_{c,t}}(1-\kappa)\left(\frac{l_t}{d_t}\right)^{1-\rho}$$

$$\frac{R_t - R_t^b}{R_t} = \frac{u_{l,t}}{u_{c,t}}\kappa\left(\frac{l_t}{b_t}\right)^{1-\rho}$$

where liquidity services are defined as $l_t = [(1-\kappa){d_t}^{\rho} + \kappa{b_t}^{\rho}]^{\frac{1}{\rho}}$, d_t are holdings of real deposits, b_t are holdings of real government bonds, and R_t is now a theoretical risk-free rate which does not incorporate a liquidity premium ($0 < \rho \leq 1$ and $0 \leq \kappa \leq 1$ are model parameters). Other things equal, both spreads are now decreasing in the stock of the relative asset, i.e. they fall when liquidity is more abundant. An increase in either asset also tends to reduce the spread on the other.

The second modification is to assume that financial intermediaries, beyond reserves, hold the entire stock long-term government bonds, that are subject to interest rate risk – in other words, households' holding fees are prohibitively high. For simplicity, short-term government bonds will be held only by households.

Using again the Friedman rule intuition, in this model households' demand for liquidity could be satiated through a sufficiently high supply of short-term government bonds and independently of the quantity of bank deposits. For given stock of government debt, for example, the Treasury could swap long-term bonds for short-term bills to meet households' desire to hold liquid assets. Given the (even if imperfect) substitutability between short-term bills and bank deposits, very large amounts of the former asset could in theory drive the liquidity premium to zero without any central bank intervention.

Taking as given the behaviour of the Treasury, is it alternatively desirable for the central bank to purchase long-term government bonds from financial intermediaries, again with the objective to satisfy the demand for liquidity? This will only be the case if government bond purchases do not only provide reserves to financial institutions, but also trigger the creation of additional liquidity, in the form of deposits, for the household sector. Since reserves are not exposed to interest rate risk, central bank purchases of long-term bonds from financial institutions do relax the leverage constraint and allow the creation of additional deposits. Hence, extended liquidity policy is desirable. In theory, it should reach the point where all long-term government bonds are held by the central bank. In practice, this conclusion abstracts from other considerations, such as the impact of a large balance sheet for financial risks, that will be discussed in Section 4. Here we simply assume that political economy constraints prevent the central bank from holding the entire stock of government debt.

As far as interest rates are concerned, outcomes are qualitatively similar to Section 3.2. First, it remains infeasible for the central bank to close the $R - R^d$ spread though the setting of the interest rate on reserves. The creation of deposits remains costly for financial institutions, due to their leverage constraint. Second, the $R - R^m$ spread between will remain positive.

To conclude, extended liquidity policy, in the form of targeted purchases of long-term government bonds from financial institutions, is desirable from the perspective of satisfying households' demand for liquidity. The supply of reserves would increase accordingly and so would the size of the central bank balance sheet.

3.4 Implications for central banks

The simple theoretical model sketched above can be useful for the assessment of the desirable features of the reserves-supply policy in the long-run.[9] From this perspective, households can be interpreted more broadly as the non-financial private sector.

A first lesson from our simple model is that setting the remuneration of reserves at the same level as the risk-free rate – a version of the Friedman rule – is not always desirable. Optimality requires minimising the opportunity cost of liquidity for the non-financial private sector. Since this sector cannot hold reserves, setting the interest rate on reserves equal to the risk-free rate would not, per se, achieve the intended objective. If liquidity is only provided to the non-financial sector by bank deposits, then bank deposits are the asset whose return should be set equal to the risk-free rate. However, this is infeasible if banks are subject to leverage constraints on their total assets. As a result, the opportunity cost of holding deposits will remain positive. This will also be the case if liquidity services are additionally provided by short-term government bonds since their supply cannot be adjusted by the central bank.

A second lesson from our simple model is that it may be desirable for central banks to implement an extended liquidity policy, i.e. to foster the creation of liquidity for the non-financial private sector by purchasing risky assets, notably longer-term government bonds, from financial institutions. By swapping these assets for reserves, banks would reduce their effective leverage and could attract funding at lower rates. In turn, lower rates on bank deposits would increase their quantity and help satisfy the demand for liquidity of the non-financial private sector.

[9] For a broad overview of benefits and costs of the reserve-supply policy in the long run, see Lane (2023).

4 Challenges of an extended liquidity policy

An extended liquidity policy implies that the central bank's balance sheet is lengthened, with large amounts of bonds or loans on the asset side and reserves on the liability side. This exposes the central bank to credit and interest rate risk. As a result, the central bank may make losses. In this section we ask to what extent these risks matter.

4.1 Central bank solvency

Central banks have the unique ability to issue money. They can thus not go insolvent in a narrow sense. But this doesn't mean they must not be concerned about their solvency, because they cannot issue money at will while hoping to maintain price stability. That is, if the central bank prints too much money it loses control over inflation. There are two reasons why the central bank may lose its control over inflation. First, the fiscal authority may demand high seigniorage payments, which are only feasible by increasing the quantity of money. This situation is described in in the fiscal theory of the price level under fiscal dominance (Leeper (1991)). Second, the central bank may make large losses on its own operations, which the fiscal authority is not ready to make up for by a fiscal transfer to the central bank. This situation is described as a financially independent central bank lacking fiscal support (Del Negro and Sims (2015)). When evaluating the merits of a larger central bank balance sheet, it is the latter case that requires particular attention, because a larger balance sheet involves larger financial risks.

A financially independent central bank can only fulfil its price stability mandate as long as intertemporal solvency is guaranteed, that is, if the present value of future seigniorage revenues is higher than the current stock of interest-bearing liabilities net of the central bank's assets. This concept of solvency is significantly more generous than solvency by conventional accounting standards. That is, in principle there is no economic reason why a central bank cannot operate with negative book equity while maintaining control of inflation – indeed, some central banks do just that. However, in practice negative book equity may become a political problem when legal rules force the treasury to recapitalize the central bank on that occasion (as is the case for some NCBs) or when the public loses faith in the central bank on that occasion. As a result, central bank independence may be revoked and with it the successful taming of inflation archived by central bank independence.

Both forms of insolvency therefore represent a risk to central bank independence and its inflation mandate. While there is large uncertainty about the value of seigniorage, it is typically estimated to exceed the book value of equity by a large multiple. According to the estimates of Buiter and Rahbari (2012) the ECBs comprehensive net worth including seigniorage was around 60% of euro area GDP in 2021, while its book equity was 5%. In the same year the ECB's balance sheet peaked at around 70% of GDP. Estimates for the FED by Del Negro and Sims (2015) and Reis (2016) are of the same order of magnitude. Furthermore, since higher interest rates are associated with higher inflation, the value of seigniorage tends to go up exactly when interest rate risk materialises, which represents a natural hedge (Del Negro and Sims (2015)). This has led economists to believe that the risk of intertemporal insolvency is rather low, even with balance sheets of the order of magnitude common since the global financial crisis (Del Negro and Sims (2015), Hall and Reis (2015), Debrun et al (2021)). Accounting insolvency however is a much more likely political risk to consider.

4.2 Managing solvency risk

An extended liquidity policy would expose the central bank to such risks and thus requires an appropriate backing. Such backing can be a credible promise to recapitalize the bank by the fiscal authority – which may be politically difficult – or a sufficiently large amount of central bank equity. And not only should the central bank be able to comfortably shoulder the risks deriving from its liquidity policy, but it should also be able to support large additional risks, which the central bank might need to assume in times of crises to engage in emergency measures (e.g. APP, LOLR).

These considerations restrict the scope for an extended liquidity policy. Furthermore, they favour a composition of the balance sheet tilted towards more secure assets and towards lower maturity transformation. Lending operations, i.e. collateralised loans to banks, are typically less affected by credit risk than outright asset purchases: Both the lending bank and the collateral need to fail, plus there is over-collateralisation. Lending operations are also less affected by interest rate risk, since lending is typically of shorter maturity, while outright purchases are often longer term. However, sovereign crises often involve banking crises (Gennaioli et al (2014)). Thus, in case of a sovereign crisis, collateralisation of lending operations by sovereign debt may deliver less additional safety over outright purchases than hoped for.[10]

Aside from risks, another question is which balance sheet configuration favours central bank profits and thus the build-up of equity buffers against risk through the cycle. A minimal liquidity policy yields a high spread between lending operations and the deposit facility rate, but the base on which this spread is earned is small (reserves). An extended liquidity policy with a large, risky outright portfolio is likely to yield higher profits on average. This can ameliorate the concerns mentioned above, since it allows the central bank to build an equity buffer over time.

Furthermore, the experience of the past decades has shown that central banks tend to deviate from minimal liquidity regimes when they hit the zero lower bound. A minimal liquidity regime can thus be expected to be temporarily abandoned by the

[10] Currently, ¾ of collateral posted at the ECB is private debt, the share of sovereign debt could increase in case of a sovereign debt crisis.

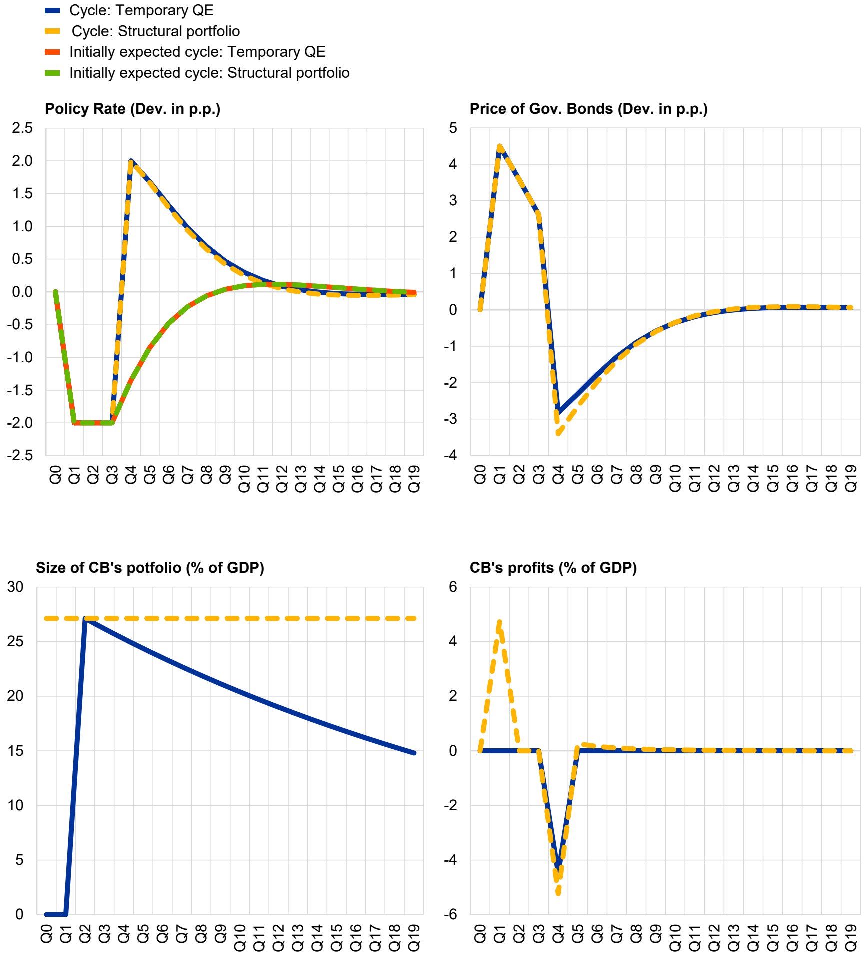
implementation of QE whenever the ZLB holds. Plus, in the past central banks have opted for a sequencing of exit from QE and the ZLB, whereby they first raised rates and then gradually offloaded the assets. One may be concerned that such a policy (minimal liquidity in normal times, QE at ZLB, lift-off before QT) implies that the central bank typically “buys high and sells low”. If one focusses exclusively on interest rate risk, this concern may indeed be justified. To the extent that the normalisation of policy rates is faster than what was anticipated when the assets were purchased, policy normalisations lead to the materialisation of interest rate risk and balance sheet losses. Figure 4 illustrates such a stylised scenario on the basis of the Karadi and Nakov (2021) model. In this scenario, the central bank purchases assets after hitting the ZLB and then hikes the interest rate above normal levels, which was not originally anticipated. This scenario captures the experience of the euro area during the last decades. The central bank makes balance sheet losses when the rates are unexpectedly increased (a monetary contraction).[11] We compare this to a situation where the central bank maintains a large constant balance sheet. In that case the losses upon hiking rates are compensated for by gains made previously when cutting rates to the ZLB. To the extent that the extended liquidity policy pre-empts the need for cyclical QE (as models with stock effects suggest), such a policy may thus be less prone to make losses through the cycle than a policy of minimal liquidity with QE at the ZLB.

[11] Such losses from interest rate risk only materialise if the policy normalisation is unexpectedly fast. On the contrary, if it comes unexpectedly late, the central bank will make gains.

Figure 4

Across a cycle like the most recent one, a structural portfolio may make less losses from interest rate risk on average.

Subtitle (delete if not needed)



Notes: The figure shows the responses of the Karadi Nakov (2021) model to a sequence of monetary policy shocks, roughly resembling the most recent interest rate cycle since 2008. Initially the policy rate drops to the ZLB, where it is expected to stay before it gradually returns (green & red lines in panel 1). But later an (unanticipated) steep increase in the interest rate happens before the economy converges back to steady state. In one scenario the central bank keeps a large structural portfolio. In the other, it engages in QE once the ZLB is reached and then winds down the QE portfolio gradually.

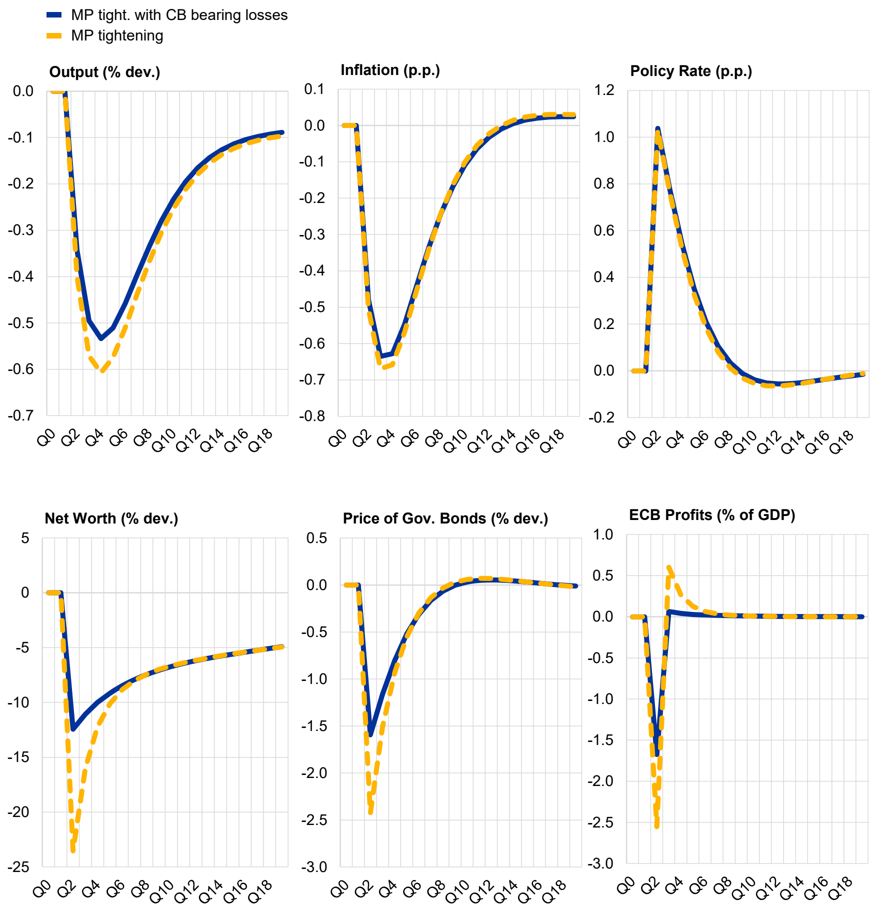
4.2.1 Side effect: Balance sheet losses as an automatic stabiliser

The balance sheet losses of the central bank are the gains of some other investor (Benigno and Nistico (2020)). Such losses are thus a redistribution from the central bank, that is ultimately the taxpayer, to the investor that would otherwise have held the respective asset. This is a specific instance of stealth recapitalisation (Brunnermeier and Sannikov, 2016), where said recapitalisation is paid for by the central bank. This redistribution can be desirable: To the extent that it relaxes the constraints of constrained agents in crisis times, it may be thought of as an automatic fiscal stabilisation tool.

In the context of the recent tightening phase of monetary policy, said redistribution may be useful to soften the impact that the monetary tightening has on financial constraints of the banking sector. Banks suffer from sudden monetary contractions due to maturity mismatch, large holdings of reserves reduce that issue (as documented empirically by Fricke et al (2023)). In doing so the large central bank balance sheet lowers the overall effectiveness of monetary policy, but it improves the sacrifice ratio, that is the costs of cutting inflation. Figure 5 illustrates this in a stylized scenario, again using the Karadi and Nakov (2021) model. We analyse a contractionary monetary policy shock, starting from a situation with a large outright portfolio. The central bank incurs balance sheet losses, which reduces the losses that the other holders of bonds, in particular banks, would have made. This reduces the contractionary effect of the monetary policy shock relative to a scenario where banks do not benefit from such a "partial insurance" against contractionary policy. However, it also improves the sacrifice ratio. That is, while a slightly stronger policy response is needed to obtain the same reduction in inflation, the costs in terms of GDP of this disinflation are lower. Note that in the model the central bank buys all bonds from domestic banks. If a part of the bonds is bought from nonbanks or international investors, the effect would be smaller.

Figure 5

Central bank balance sheet losses dampen the effectiveness of interest rate policy.



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Notes: The figure shows the responses of the Karadi Nakov (2021) model to a monetary policy shock, comparing 2 scenarios: In one case the central bank absorbs the losses on its structural portfolio. In the other case the central bank rebates those losses to banks lump sum. This way we isolate the effect of the "insurance against interest rate risk" that the central bank portfolio provides to other investors, banks in this case. Since banks are constraint agents, this insurance effect dampens the contractionary effect of interest rate policy.

4.3 The multi-country aspect of the euro area

The previous discussion and most of the existing literature focus on the case of a single country. The lessons drawn extend to the case of a monetary union. Without fiscal support, the central bank needs to remain solvent at the union level. Indeed, with fragmented fiscal policy implementing credible fiscal support may be even harder than in a single country. In the euro area this difficulty has led to the adoption of a framework for the Asset Purchase Programme (largely) without risk sharing. That is, the ECBs assets are (largely) held by individual NCBs and gains or losses (largely) accrue to the individual NCB. In this setup things get more complicated than in the single country case.

In particular, it is not enough for the central bank to be solvent at the union level. The individual NCBs need to be solvent each by themselves as well, taking into account their share of the present value of seigniorage revenues. The default of a single government of the union may not threaten unionwide solvency. But without risk sharing, it may render its domestic NCB insolvent, potentially even intertemporally. If the national government doesn't recapitalize the affected NCB, then the losses would be shared among the member states, either by an implicit transfer or by higher inflation (Bassetto and Caraciciolo, 2021). Thus, a monetary union without risk sharing does not benefit from diversification of credit risk. Rather, credit risk materialising for one individual member may affect the whole monetary union.

These considerations imply that an extended liquidity policy poses a greater threat to the solvency and viability of the central bank in a setting such as the euro area than in a single country. This issue could be resolved by risk sharing, in which case neither the central bank at the union level nor any individual NCB would be likely to become insolvent in the event of a single country's default. However, such a policy would increase default incentives (moral hazard) and would likely not be universally acceptable, given different fiscal positions across country. Common European debt would be an indirect alternative to implement risk sharing. While implementing an extended liquidity policy exclusively with European Union bonds may currently not be feasible due to insufficient amounts outstanding, relying on them as much as possible would ameliorate the issue of lacking risk sharing.

5 Concluding remarks

The main focus of this paper has been to analyse the desirability for central banks to implement an extended liquidity policy, i.e. to provide financial institutions with abundant reserves. In theory, this approach has desirable features, since financial institutions are leverage-constrained. The opportunity to hold more reserves would incentivise them to create more deposits, that constitute liquidity for the non-financial sector. At the same time, there is a risk that reserves crowd out bank lending. Moreover, an extended provision of liquidity would increase the size of the central bank's balance sheet, and increase its exposure to financial risks.

All in all, an extended liquidity policy appears to be desirable. Creating reserves in excess of the minimum liquidity needs of the banking sector would contribute to satisfy the general demand for safe and liquid assets from the broader, financial and non-financial, private sector. However, the marginal benefits of more and more reserves are likely to be decreasing, while their marginal costs are probably increasing. The extended liquidity policy should therefore be implemented in moderate amounts.

An important, open issue is how to best inject a larger amount of reserves in the banking system. In the paper, we have not discussed this issue in detail. In the euro area there is experience with two options: asset purchases and longer-term refinancing operations. Our theoretical analysis is not tailored to shed light on the relative benefits of these two options. We have however noted the advantages of refinancing operations in reducing financial risk for the central bank and in leaving convenient longer-term bonds in the hands of the private sector.

While focusing on the consequences of bank capital regulation, our theoretical analysis has also abstracted from liquidity regulation. We have only taken as given that it will have consequences on the optimal supply of reserves. It is clear that liquidity regulation will also have an impact on banks' incentives to trade in the interbank market.[12]

[12] Bech and Keister (2017) provides a theoretical analysis of these effects. Empirical evidence for the euro area is available from Kedan and Veghazy (2021).

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Appendix

This appendix provides more detail on the model sketched in sections 2.2 and 2.3.

In section 2.2, the household maximises its intertemporal utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u\left(c_t, \frac{D_t}{P_t}\right) - \frac{\upsilon}{1+\phi} n^{1+\phi} \right]$$

where c_t is consumption, D_t are nominal bank deposits, P_t is the price level, n_t are hours worked, and β, υ and ϕ are parameters, subject to the budget constraint

$$D_t + B_t + \frac{1}{2}\zeta P_t \left(\frac{B_t}{P_t} - \tilde{b}\right)^2 \leq R_{t-1}^d D_{t-1} + R_{t-1}^b B_{t-1} - P_t c_t + W_t n_t - T_t$$

Where B_t are government bonds, $\zeta P_t \left(\frac{B_t}{P_t} - \tilde{b}\right)^2$ are nominal holding costs to hold a larger amount of government bonds than $\tilde{B}$, R_t^d and R_t^b are the nominal returns on deposits and bonds, respectively, W_t is the nominal wage and T_t are lump-sum government taxes (transfers if negative).

The first -order optimality conditions include

$$\frac{R_t^b - [1 + \zeta(b_t - \tilde{b})]R_t^d}{R_t^b} = \frac{u_{d,t}}{u_{c,t}}$$

where $b_t \equiv B_t/P_t$. If $\zeta \to 0$,

$$\frac{R_t^b - R_t^d}{R_t^b} = \frac{u_{d,t}}{u_{c,t}}$$

Bank j borrows D_{t-1} from households and invests in government bonds and reserves M_t.Its profits are

$$Z_{j,t} = R_{t-1}^b B_{j,t-1} + R_{t-1}^m M_{j,t-1} - R_{t-1}^d D_{j,t-1}$$

where R_t^m is the nominal gross remuneration of central bank reserves. When deciding its asset allocation, the bank is subject to the following incentive constraint

$$V_{j,t} \geq \lambda(B_{j,t} + \delta M_{j,t})$$

Assuming that the constraint is binding, bank j's first order conditions include

$$R_t^m - R_t^d = \delta(R_t^b - R_t^d)$$

$$\frac{z_{j,t}}{\theta + \omega} = \frac{1}{1-\delta}\left[(R_{t-1}^b - R_{t-1}^m)\phi_{j,t-1} - (\delta R_{t-1}^b - R_{t-1}^m)\right] z_{j,t-1},$$

where $z_{j,t}$ is the bank's real net worth, $\phi_{j,t}$ is bank leverage (total assets divided by net worth), and θ and ω are structural parameters. Assume utility takes the isoelastic form $u_t = \frac{c_t^{1-\sigma}}{1-\sigma} + \frac{d_t^{1-\chi}}{1-\chi}$. Households' demand for deposits can be rewritten as

$$d_t = (1-\delta)^{\frac{1}{\chi}} \left(\frac{R_t^b}{R_t^b - [1 + \zeta(b_t - \tilde{b})] R_t^d} \right)^{\frac{1}{\chi}} c_t^{\frac{\sigma}{\chi}}$$

In steady state, this equation can be combined with the two first order conditions of the bank to obtain

$$\frac{R^m}{R^b} = 1 - (1-\delta) \frac{1}{\phi - 1} \frac{\frac{\beta}{1 + \zeta(b - \tilde{b})} - (\theta + \omega)}{\theta + \omega}.$$

If $\zeta \to 0$,

$$\frac{R^m}{R^b} = 1 - (1-\delta) \frac{1}{\phi - 1} \frac{\beta - (\theta + \omega)}{\theta + \omega}.$$

In section 2.3, the household maximises

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u\left(c_t, \frac{D_t}{P_t}, \frac{B_t}{P_t}\right) - \frac{\upsilon}{1+\phi} n^{1+\phi} \right]$$

where c_t is consumption, D_t are nominal bank deposits, P_t is the price level, n_t are hours worked, and β, υ and ϕ are parameters, subject to the budget constraint

$$D_t + B_t \leq R_{t-1}^d D_{t-1} + R_{t-1}^b B_{t-1} - P_t c_t + W_t n_t - T_t$$

that is different from the one in section 2.2 because it assumes $\zeta = 0$ for short term government bonds, and $\zeta^L \to \infty$ for long-term government bonds.

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Peter Karadi
European Central Bank, Frankfurt am Main, Germany; email: peter.karadi@ecb.europa.eu

Dominik Thaler
European Central Bank, Frankfurt am Main, Germany; email: dominik.thaler@ecb.europa.eu

Oreste Tristani
European Central Bank, Frankfurt am Main, Germany; email: oreste.tristani@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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